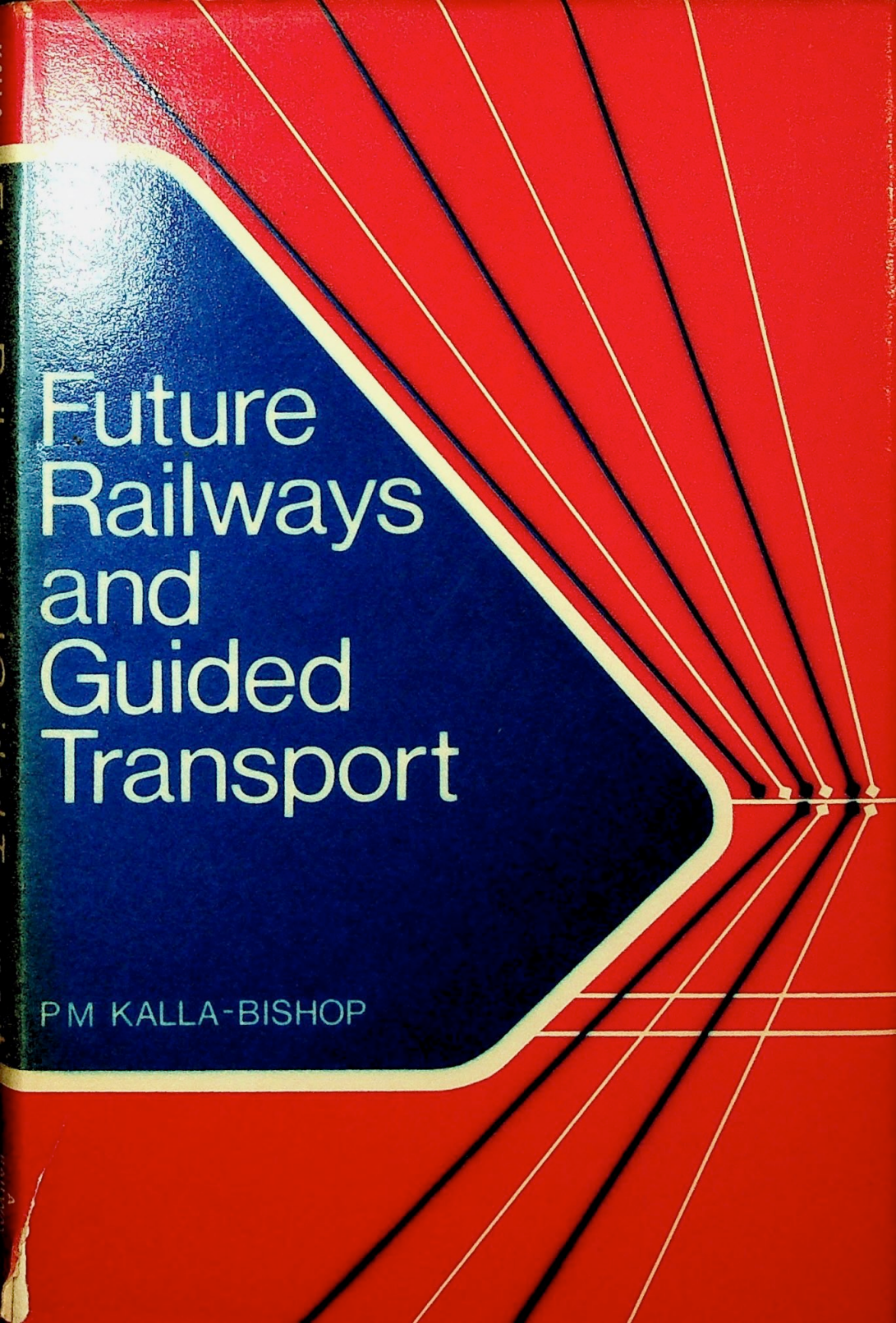




Future Railways and Guided Transport

PM KALLA-BISHOP

ABOUT THIS BOOK

Current interest in the environment and in pollution problems has led to renewed interest in railways because of their potential contribution to the quality of life. Within their range fast and economical transport is offered with minimal noise, dirt and hazard. This book for the general reader describes the impact of modern technology on the transport mode in non-technical terms and sets out the possibilities now within reach. The term railway is liberally interpreted and all forms of guided transport are examined and briefly assessed, including hovertrains, magnetic levitation lines, evacuated tubes and other fresh ideas now being put forward. Both the new modes and the orthodox railway are placed in a general transport organisation background.

Motive power, signalling (soon to be called command and control), high speed trains and unorthodox transport systems are looked at in turn. The author describes present advanced practice—in all parts of the world and where necessary briefly relating how the practice was developed—before showing where the new techniques are leading. Both the orthodox railway and the unorthodox modes will be fully automated for intensive traffic in

future, with driverless trains controlled from widely dispersed centres. Just how this automation will be attained is set out here and the results noted.

A Railway Magazine book

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Future Railways

An adventure in engineering

P. M. KALLA-BISHOP

A RAILWAY MAGAZINE BOOK
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Opposite: Trial train of the Bay Area Rapid Transit, San Francisco, in an unfinished station. The line opened in 1972 (see Chapter 5)

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rail mode is a leader in the application of new ideas and what the orthodox railwayman is now doing will be available to the newer modes to their great benefit. These newer modes are not neglected and their features are described, although it must be admitted that no attempt has been made to cover every inventor's or promoter's minor variation on the transport theme.

It is frequently said that the heyday of the railway was in the years before 1914, or so it is said in Great Britain where this book is being written. It all depends on what is meant by heyday, in the well-known phrase. I am just old enough to have visited the Cornish seaside resorts when they were bereft of a water supply system, main drainage and electric light. Cornwall had been served until a few years before solely by railways in their heyday, but because of the inadequacy of this transport system and because not enough people lived in the area the provision of the common amenities was not worth while. The internal combustion engine running on the road brought water, drainage and light to Cornwall, to the great benefit of its inhabitants, yet today the road transport mode has outlived its welcome and the population is beginning to wonder if a mish-mash of motor-cars all over the place is not too high a price to pay. It is impossible to please everyone all the time when providing transport and all transport men are familiar with the problem of fending off the complaints of a minority, with the quite inadequate excuse (which in any case is obviously not believed) that the minority only suffers because the great majority is well pleased.

The above paragraph is not intended to denigrate the efforts of the railways in their heyday, but it does illustrate that no one transport mode can meet all the transport needs of a nation. Thus the rise of the railways as a cheap means of transport in the early nineteenth century brought about the end of the British canal age, canals now only survive for the performance of specific tasks and there are very few of them. It is true that canals were advocated as a cheap means of transport right up to 1930 or so, if not afterwards, but this was due to historical factors. The canal system had been largely built before or during the Napoleonic wars, wars that brought about a depreciation of the currency. Thus the servicing of the capital became very cheap in relation to the assets held with consequent economy and an increased ability to offer low freight rates. Studies have shown that in fact the canal is the most expensive form of land transport, unless the canals are supported by a large system of easily navigable rivers, which river system does not exist in Great Britain although other European countries are more fortunate.

To say baldly that railways are cheaper than canals does not spell out all their advantages. Usually early railways were less costly to build than canals and when built they offered far more expeditious transport. Above all they were more flexible than the previous canal and coastal shipping transport modes and far superior in speed to the early nineteenth century road transport mode. Railways were built in every country and to every major centre throughout the world, for cheap and expeditious transport was the nineteenth century contribution to the industrial revolution which had been started in Great Britain during the previous century. With the coming of the twentieth

century a transport rival to the railway appeared, the internal combustion engine running on a road. The road transport mode thus reinforced proved far more flexible than rail and this flexibility has been exploited to the full, there are few places that cannot be reached by motor car or lorry. Even although it can be demonstrated on paper that other transport modes are cheaper, road transport often has been preferred because of the readiness of its vehicles to go anywhere and because of the facility with which they can be switched from one task to another. The rail mode was rapidly deprived of much of its short haul business and a lot of the longer-haul traffic for which rail was well-suited was taken in addition. The road and rail confrontation was world-wide with much the same results everywhere.

The virtues of road transport are only too familiar, commercial interests draw the attention of the public to the pleasures and profits of the road every day and in many different manners. Perhaps its disadvantages are not so well known. First, should like be compared with like, it is slower than other land transport forms between any two given points. Flexibility of course cancels out this speed disadvantage in a small country like Great Britain where the cost of transferring from road to rail and back again is not made up for by the length of haul—always excepting bulk loads that can be readily transferred from one transport mode to another or indeed can be handled by rail transport entirely. Secondly, road transport is heavy on manpower, which is a very expensive commodity and road transport operating costs often include up to 80 per cent for it, if not more. Connected with this is the growth of automation, the techniques of which can be readily applied to the railway with consequent saving in manpower but which are not so easy to apply to the road. Indeed when attempts are made at road automation the result is something suspiciously like a railway. Lastly, road transport is now in trouble with those people, and their number is coming to include almost everyone, who are worried about the environment and the quality of life. Air pollution, smell, noise and excessive use of land by road transport is reaching unsupportable limits in crowded countries and ways and means to diminish the nuisance are eagerly sought.

Other transport rivals to the railway have appeared during the twentieth century. Airlines are manifestly superior for the longest journeys for passenger and valuable freight use. For liquid freight the pipeline has its advantages, although it requires a very high level of traffic and for that reason is perhaps one of the most inflexible of the transport modes. In Great Britain the London-Liverpool pipeline and its branches will remain perhaps the only public route, although there are many specialised pipelines between ports and refineries and between refinery and refinery for oil products. Oil companies are highly conscious of transport costs and use all the transport modes, the railways where economic get their share of the traffic. Gas pipelines and electricity power lines are other transport modes which are perhaps not immediately obvious as such. When I was young long trains of coal used to arrive in London along the railways at frequent intervals. These trains to feed the fires and factories of London no longer run, the coal is turned into

electricity nearer the coalfields, gas comes from different sources and power comes to London by other means than rail.

Through all these developments the railway has retained its competitive position for much traffic and because of the technological developments to be described in this book it is likely to improve the position in future and win back some traffics that it has lost. The position today can be summed up, at least for European countries, as follows: In the passenger field rail is pre-eminent for distances of, say, seventy-five to three hundred miles. For daily journeys to and from work the lower limit drops to about ten miles and for mass transport inside cities to less than one mile. For freight, rail is the preferred mode for all forms of bulk transport, the minimum distances the loads are carried varying with the bulk, ease of loading and unloading and weight. With the same provisos rail is considered suitable for freight transport over distances greater than, say, three hundred miles in wagon load lots, but the distance the load is carried can vary downwards to a far greater degree than is the case with bulk transport, according to the goods carried and whether or not it is industrial siding to industrial siding traffic between consignor and consignee. The advent of the container is of great interest to the rail mode, for by its use much traffic which would fall outside the rail mode can be converted into a bulk traffic which falls inside its scope. Finally, there are regular parcels and other small load traffics which call for speed and dependable delivery. These too are suitable for rail, provided that the traffic is regular and much the same amount for the same destinations has to be handled every day. All these assessments of suitable traffics are based upon averages and it may well be that for any particular traffic it can be shown that one particular consignment could be carried more cheaply by road, while excessive profit is being made on another. But note that road prices too are based on averages and should the mode be able to quote a price cheaper than rail it may be that the load is carried at a loss.

A profitable railway derives its income from a vast diversity of traffics, the fares and rates for which are all to a greater or less degree averaged out, so that often there is concealed cross-subsidisation. In a simple example let a railway carrying passengers, iron ore and hardware products between two towns 200 miles apart be postulated. Receipts from passengers and iron ore at true costs of carriage cover nearly all costs, receipts from the hardware traffic make up the rest of the costs and provide the profit. A road haulier abstracts the hardware traffic by offering door-to-door service, even although the journey is slower and the rates remain the same. The railway then operates at a loss and should vanish from the scene. In practice the railway puts its rates up for the iron ore, which is not easily carried by road, leaving the fares for the passengers the same for they may take to the rival mode. In short the passenger fares are cross-subsidised by the iron ore rates. In the artificial circumstances of this sort of economic model one can say too that more costly transport for iron ore will be reflected eventually in more costly steel hardware products and that what price advantage has been gained by cheaper transport has been dissipated.

In real life the railway does not handle three types of traffic over a given stretch of railway but hundreds. Determining the true cost of transport for each and every one of these traffics is impossible, for the number of man hours consumed in taking out the necessary figures and in doing the calculations would be vastly out of proportion to any economic benefit gained. Hence resort is had to averages, an average cost is determined to provide and operate various types of railway and average rates and fares are worked out sufficient to pay the costs and provide some profit for the whole railway system. If in spite of this there is a loss there is difficulty in putting a finger on just what is wrong because of the complexity of the figures. Faced with this sort of situation those responsible for transport operations have little option but to fall back on encouraging those sort of traffics for which the railway is in theory a favourable form of transport.

Road transport costs are in not much better shape, largely because in Great Britain as in most other countries there is a gulf fixed between those who pay for the provision and maintenance of roads and those who operate the means of transport upon them. This can be exemplified by a 1971 proposal by road haulage interests for a fast trunk lorry service up and down the motorways of Great Britain between centrally-sited depots. The trunk services would be run by much larger lorries than now permitted and ordinary-sized lorries would deliver customer's goods to the depots and pick up goods for delivery. The scheme turned on the running of the large lorries, but they have yet to be authorised by the government and it is a fair deduction that the government, which is also responsible for the maintenance of the motorways, realises that any profit in the scheme would be more than swallowed up by increased wear and tear on the road surface. The road hauliers could estimate the profits they would make by such a scheme but they know nothing of road maintenance, so they have not got the full picture. It is indeed a fairly common sight in Great Britain to see a heavy lorry knocking road surfaces, pavements and street furniture to pieces with scarcely a second thought, road hauliers have no financial responsibility for such things.

Added to the vagueness about true costs is the difficulty that the various transport modes overlap extensively, thus a railway can serve most parts of Great Britain with an equal facility to that of an aeroplane. In the past the British railway system met a large part of the transport requirements that are now carried out by the road transport mode. British road interests claim in their more parochial and euphoric moments that road could carry all British internal traffic and that a rail network is unnecessary. They except a few short stretches of railway for special traffics, iron ore between a port and a steelworks for example. Technically they are probably correct, but there is the major objection that undoubtedly the universal use of road transport would be more expensive for the country as a whole, quite apart from the devastating effect on the environment and the consequent discomfort for the population at large. The proposal also assumes the willingness of many people to change their habits, thus city centres would decay and offices and industry would be decentralised because of the inability of road transport to move

large numbers of people without destroying the very city it tries to serve.

Perhaps too gloomy a picture has been painted of the difficulty of arriving at true transport costs. A number of countries (more particularly Latin countries) set up empirical and arbitrary systems of cost statistics which are used to settle which transport mode shall be used in a given situation to the apparent satisfaction of all concerned. Provided that the statistical system selected gains general approval and that it does not depart too far from the intelligent deployment and economical use of resources such systems work well enough, particularly if the rules can be bent if they are obviously against common sense, a process referred to as *dérogation* in France. It is essential of course that the collection of data for these empirical systems must be simple and inexpensive. The advent of the computer with its ability to correlate and present large quantities of data has given new life to cost data systems and enabled a much closer view to be taken of what is actually happening—with the result that those who have to decide on how much of this or that transport mode must be provided can shave national costs of transport ever more closely. The development is to be welcomed, always provided that a watch is kept on the cost of collecting and processing data so that it does not exceed any possible savings.

It is into this vague cost background that some new transport modes have been injected in recent years, two major modes being hovertrains and magnetic levitation vehicles. Both these hope to provide faster passenger services and possibly faster carriage of freight compared with existing land transport modes, although as will be seen the existing orthodox rail mode can claim to equal if not to exceed the speeds reached. Studies have been made of the commercial possibilities of these new transport modes and one such on hovertrains made in Great Britain has shown to its own satisfaction if not to other people's that the hovertrain should be competitive with existing transport modes. Specifically it is claimed that hovertrains will compete successfully with orthodox railways over distances greater than one hundred miles and successfully with aircraft over distances less than four hundred miles. No account was taken of the possible future development of railways as described in this book, although some mention was made of future aircraft which might push the upper mileage limit downwards. Unfortunately for the promoters of these new modes the very technology which makes them possible will also allow considerable improvements to be made to the orthodox railway as a transport mode. Squeezed between railways and aircraft it may well be that hovertrains and magnetic levitation vehicles will be stillborn, for all forms of transport overlap greatly in their ability to move passengers and goods.

Railways in all their forms have the great advantage that they are susceptible to automation to the highest degree; an important point in a Europe where the wage cost component of the total operating cost reaches anything from fifty to seventy per cent as at today; the comparable percentage for the road mode being something like eighty. In parentheses, the fifty per cent rate applies

to the Spanish National Railways System while the seventy per cent rate applies to the German Federal Railways. The spread of percentages correlates almost but not quite with the standard of living of the country concerned and the subject is suggested as the basis of a doctoral thesis by those aspiring to an economics PhD. Due notice will have to be taken of the fact, and an explanation given, of why the comparable figures for United States' railroads are usually a good ten points below the European, although that country has the highest living standard of all. Another out-of-the-way statistical observation is that the number of breakdown cranes owned by any European railway also correlates with the standard of living, possibly because if labour is cheap it is really not worth while investing in breakdown cranes to clear up railway accidents.

Enough of economics, the following chapters will describe the more advanced equipment and techniques now being used by orthodox railways, with a survey of the proposals for unorthodox railways. In addition there will be a look at the near future as foreshadowed in the various railway development plans and the intentions behind them. It is these techniques and plans which will allow the railway to take traffic off the road on the one hand and out of the air on the other, with the overall aim of reducing the cost of transporting passengers and goods in most parts of the world. One final note to close this chapter. Various maximum speeds are quoted which as often as not are rather odd figures, 155, 185 and 310 mile/h as examples. Most railways in the world, except a few in the United States, now use the metric system and these quoted speeds are the results of conversions from 250, 300 and 500 km/h, which are the good round figures that one might expect. The standard abbreviation V is used for volts and c/s denotes cycles per second.

CHAPTER TWO

Motive power

Two major forms of motive power are used by the world's railways, the electric locomotive and the diesel locomotive. The electric locomotive draws power from an overhead contact wire or a third rail, both of which are fed in turn from electricity generating stations that as often as not are part of a national power network. The diesel locomotive on the other hand is a self-contained unit, which if using electric traction motors generates the current for them on board. Both forms of motive power can be installed in passenger carrying vehicles, which if electric are then called motor-coaches and if diesel are called railcars. Electrification of a railway calls for a high capital expenditure at first on all the equipment, but thereafter the running costs are low and there are other advantages such as maximum operational flexibility and cleanliness. Compared with electrification the use of diesel power offers a relatively low first cost but higher operating costs.

The choice of motive power for a railway, electric or diesel, depends on the amount of traffic carried. Below a certain level it is cheaper to use diesel locomotives, above the level it is cheaper to electrify. The Soviet Union Railways, for example, takes the level to be fifty to fifty-five trains each day over each line of track of the railway involved as a rough guide, but this even in the Soviet Union can vary from railway to railway. It may be that the railway runs through mountainous country with many sites to generate cheap hydro-electric power, which would favour electrification at a lower traffic level, or on the other hand the railway may serve oilwells and refineries, in which case the traffic level might be pushed up. An example of a railway about to be electrified because of rising traffic is the western end of Canadian Pacific Rail's trans-Canada route over the 627 miles between rail yards in Calgary and Vancouver, crossing the Rockies and other mountain ranges. Currently traffic amounts to 11 trains each way daily, three of them travelling west carrying export coal mostly destined for Japan. Because of the build-up of coal traffic it is expected that by 1980 there will be a requirement for 30 trains each way daily over the single track of the route. The 13,600-ton, 105-wagon, coal trains of today are powered by 3,000 hp diesel locomotives (two at the head of the train and five pairs of locomotives cut in down the train's length) and with this motive power the trains are able to maintain

15 mile/h up and down the long gradients of the line. After electrification, planned at single-phase 50,000 V industrial frequency alternating current, only six locomotives will be needed for each train and the 15 mile/h speed will be raised to 25 mile/h. The economy resulting from the reduction in the number of locomotives is startling enough but the 66 $\frac{2}{3}$ per cent increase in speed is far more important, for it is by this means that the line capacity will be increased to accommodate the expected 30 trains per day.

ELECTRIFICATION SYSTEMS

Railway electrification started with a little demonstration line in the Berlin Trades Exhibition of 1879, designed by Werner von Siemens. This was followed in 1883 by two small public railways, Volk's Electric Railway, a short line along the seashore at Brighton in England which still survives, and the Giant's Causeway & Portrush Railway in Ireland. Electrification of tramways and small railways gained momentum in the 1880s and 1890s, a notable line being the world's first deep level underground 'tube' railway, the City & South London Railway of 1890 which was only made possible by electrification. The first main line railway was electrified in 1895, a short section of the Baltimore & Ohio Railroad through a tunnel under the city of Baltimore in the United States. All these railways were direct current (d.c.) electrifications using a comparatively low voltage, not more than 650 V. This was in accordance with the state of the electrical engineering science of the time.

Meanwhile there had been progress in the generation and distribution of electric power and it had been determined that the most economical way to do both these tasks was to generate three-phase alternating current (a.c.). Furthermore the three-phase asynchronous electric motor was, and still is, the simplest and thus the cheapest type of electric motor, with the additional advantages for traction purposes that it is lighter and usually of less physical dimensions for a given power output than the d.c. and single-phase a.c. traction motors normally used. Using three-phase power involves three wires (one for each phase) to complete electrical circuits instead of two and thus when three-phase electrification was applied to railways, two overhead wires insulated from each other were involved, the third phase being represented by the earthed running rails. The first railway to be three-phase electrified was between Burgdorf and Thun in Switzerland in 1899 and from 1902 it was taken up on a large scale in Italy, principally in the north-west of the country and on the initiative of Kálmán Kandó, chief engineer of Ganz Electric Co of Budapest. More effective ways of electrifying main-line railways were soon evolved and three-phase electrification began to be displaced in Italy from 1934. As this is being written the last Italian three-phase sections (and the last of this sort of main-line railway electrification in the world) are being prepared for conversion to 3,000 V d.c.

It is a characteristic of the three-phase asynchronous electric motor that it runs at a constant speed according to the frequency of the alternating current

fed to it, the frequency being the number of times a.c. alternates in each second. In Italy a frequency of $16\frac{2}{3}$ cycles per second (c/s) was selected after one or two of the pioneer electrifications had used slightly different frequencies. There were two reasons for the selection of this comparatively low frequency, first, insulation problems were lessened and insulation techniques were not very advanced in the opening years of the twentieth century, and secondly, with this frequency the rotors of the electric motors turned at a satisfactory speed for direct mechanical coupling to the driving wheels of the locomotive. It follows that as the electric motor had only one speed of operation the locomotive similarly could work trains only at one speed. This disadvantage was overcome by using two traction motors in each locomotive and so varying the electrical circuitry that up to four speeds could be obtained for each locomotive, usually $23\frac{1}{4}$, 31, $46\frac{1}{2}$ and 62 mile/h for passenger locomotives and $15\frac{1}{2}$ and 31 mile/h for freight locomotives.

The disadvantages of the three-phase railway electrification system were quickly seen and almost simultaneously with its appearance a single-phase a.c. electrification system was developed. Roughly, single-phase a.c. is obtained from two of the phase wires of a three-phase circuit, always providing that another single-phase circuit is connected across one of these wires and the remaining phase wire to equalise the load on the three-phase circuit. A small single-phase electrification was carried out in Germany in 1903 and the single-phase traction motor in almost its modern form appeared on an experimental Swiss electrification between Seebach and Wettingen in 1906. The simplicity of the three-phase asynchronous electric motor had to be abandoned, but one overhead contact wire instead of two and freedom from electric motor running speed limitations more than made up for this. As with three-phase electrification the single-phase frequency adopted was $16\frac{2}{3}$ c/s because of traction motor design problems. Single-phase electrification was a success and it is now used throughout Switzerland, Austria, Germany, Sweden and Norway. In the United States single-phase electrification was also developed from 1907, with the modification that a slightly higher frequency was used, 25 c/s. Today some of the Penn-Central system is single-phase electrified, notably its trunk route between New York and Washington.

Both the three-phase and single-phase systems of railway electrification were more economical for main lines than direct current electrification in their day, although the latter system of electrification continued to be extended in its turn as it was the most economical form of electrification for heavy suburban passenger traffic carried over short distances. This despite the necessity of converting industrial frequency three-phase current to direct current by the rather cumbersome method of using a three-phase motor in a sub-station to drive a dynamo to produce direct current, a process that lost up to 20 per cent of the power originally generated. Despite various experimental electrifications at high voltages a voltage higher than 750 was not generally used, although in 1916 the Chicago, Milwaukee, St. Paul & Pacific Railroad opened the first extensive high voltage line at 3,000 V d.c. in the rather specialised conditions of crossing the Rocky Mountains. It was not

until the early 1920s, with the coming into use of the ultra-rapid circuit breaker and the mercury-arc rectifier, that high voltage d.c. railways became economically possible over long distances and out-performed the rival single-phase system. The ultra-rapid circuit breaker protected delicate circuitry in case of unforeseen heavy currents while the mercury-arc rectifier offered a means of direct conversion of three-phase current into d.c. with a great reduction of the previous losses. Since the 1950s the advent of the solid-state silicon diode rectifier (an application of electronics) has improved the position still further. Raising the voltage to 3,000 V d.c. allows expensive sub-stations to be sited farther apart, up to 25 miles compared with five to six miles necessary with 750 V, at the expense of rather more complicated locomotives. For main lines carrying very heavy traffic 1,500 V d.c. is used; the sub-stations must be built closer together but the locomotives are simpler and therefore not so costly.

Electricity is normally generated at 50 c/s (known as industrial frequency) in most parts of the world, except in North America and Japan where 60 c/s is preferred. The frequency of electric current is determined by the design of the generator and the speed at which it is run. Running a generator faster than is necessary for, say, 60 c/s would result in increased frequency but also in increased voltage, which in turn might lead to increased insulation problems. On the other hand running the generator more slowly than 50 c/s and using the output for lighting would result in flicker; if the 'railway' frequency of $16\frac{2}{3}$ c/s is used for lighting the flickering of lamps is very pronounced indeed. So frequencies in the range 50–60 c/s are the most satisfactory for industrial current generation, although as it is sensitive Americans crossing the Atlantic are apt to complain about the flickering lights of Europe. In the previous paragraph it was noted that losses in power occur when current is rectified from three-phase as generated to direct current. Similar losses also occur when converting the generated 50 c/s current to the railway frequency of $16\frac{2}{3}$ c/s. Savings could be obtained by using single-phase 50 c/s current direct for railway electrifications, a point that was appreciated by the pioneers and several attempts were made to do it in the early 1900s with little success. The state of the electrical engineering art at that time was not far enough advanced for main line 50 c/s electrifications, although one or two tramways and minor railways were made to work.

The first successful main-line single-phase industrial frequency locomotive was designed by Kálmán Kandó of the Ganz Electric Co in Hungary in 1923 and tested on ten miles of specially electrified main line near Budapest. Subsequently, 116 miles between Budapest and the Austrian frontier at Hegyeshalom were electrified at 16,000 V, single-phase 50 c/s in 1932–33. Kandó and his company Ganz Electric as previously noted were behind the initiation and the spread of three-phase electrification in Italy from a couple of decades before. In Kandó's locomotives (MÁV V40 class) the 50 c/s current from the overhead line was led to an electro-mechanical phase converter with an output of three-, four- and six-phase current, which was fed in turn to an asynchronous traction motor coupled direct to the driving wheels. Two

different traction motor pole groupings were provided for the three-phase input, so that two different speeds were available, which together with the speeds provided by the four- and six-phase currents gave the locomotive four different running speeds. It will occur to the reader that another way of obtaining different locomotive running speeds would be by supplying the asynchronous traction motor with current at different frequencies. Unfortunately electro-mechanical methods of frequency conversion tend to be cumbersome and heavy, nevertheless it was attempted in Hungary and a locomotive was produced in 1944 (MÁV V44 class). This locomotive was destroyed during the 1944 siege of Budapest but during the 1950s a dozen frequency conversion locomotives were put into traffic (MÁV V55 class). In these locomotives a phase converter produced three-phase current for the electro-mechanical frequency converter, which was mounted on an extension of the phase converter's rotor shaft. The frequency converter supplied current at five different frequencies to the lightweight asynchronous traction motors (one for each axle) so that the locomotive had five operating speeds. Frequency conversion using more sophisticated methods appears to have a great future as noted below.

Further experimental work was undertaken on single-phase industrial frequency electrification in Germany from 1934, Russia from 1938 and in France after the second world war. Two different methods were tried to use the industrial frequency current in a locomotive. One method was to feed it to a 50 c/s motor (the design of the motor was such that it could not be used for traction direct) which in turn drove an a.c. generator to produce current for asynchronous traction motors. This worked very well, but the losses inherent in generating electric current twice, once in the generating station and once on board the locomotive, made it economically unattractive. In the second method the current from the overhead wire was fed to a transformer which cut its voltage to that suitable for the traction motors and then passed it to a mercury-arc rectifier. The d.c. current output was fed to normal d.c. traction motors, with their ability to function more or less efficiently over a wide range of locomotive speed. This latter method of powering a locomotive was a great success, the savings envisaged for industrial frequency electrification were realised almost to the full and from 1952 or so the system became the preferred method of main line electrification. In Kálmán Kandó's day a generation before the mercury-arc rectifier was not developed sufficiently to be able to appear on his locomotives, as it was then too bulky and delicate, and indeed since 1961 it has been superseded on locomotives by the solid-state silicon-diode rectifier, with a still further gain in efficiency. Since 1952 many railway electrifications at 50 c/s or 60 c/s have been carried out in countries all over the world, it is now the most desirable system. The Czechoslovakian State Railways (ČSD) has electrified a considerable proportion of the railway mileage in its country over the last 20 years, at first it used 3,000 V d.c. and then it used latterly the new industrial frequency. Taking capital costs and operating costs together the ČSD reports that industrial frequency shows a 23 per cent saving over 3,000 V d.c. electrifications. This high figure

may owe something to local conditions inside Czechoslovakia but it is quoted as an indication of what is possible.

For the moment, then, 25,000 V single phase 50 c/s is the most desirable electrification system, the voltage being the highest that can conveniently be handled with existing insulation techniques. Power carried in a 25,000 V cable can arc over an air gap of several inches too, should another conductor be brought too near, which has given rise to clearance difficulties on occasion when the live catenary cable carrying the overhead contact wire has had to be passed under bridges and through tunnels. Nevertheless, Canadian Pacific Rail is proposing to double the voltage to 50,000, to allow sub-stations to be spaced farther apart for even greater economy in the electrification mentioned at the start of this chapter. Presumably there are no overbridges or other confined clearances along the route and it so happens as a stroke of luck that the 5 mile 39 yd Connaught Tunnel opened on the line in 1916 was given a height far beyond normal by the builders to provide for the easy clearance of the smoke and steam from the locomotives of those days, so that there will be no trouble there. As well as industrial frequency electrification, 750 V d.c. remains the most economical method for railways not more than ten or twelve miles long; in practice it is used for metropolitan lines in cities. This is because low voltage d.c. equipment both on the locomotive and by the lineside is simple and cheap. The difficulty is that the low voltage gives rise to very high currents, particularly for heavy or fast trains, and the handling of these high currents over longer distances than those quoted sends the total cost of the electrification system upwards above that of industrial frequency. It might be added that the world's first 50,000 V railway will be the Black Mesa & Lake Powell Railroad. This is an 80-mile mineral line in Arizona, due to be opened to traffic in 1973.

Theoretically, should a railway be over twelve miles long and under twenty-five, 1,500 V d.c. should be the preferred electrification system. In practice railways of this length are either extensions of 750 V d.c. city systems or branches off industrial frequency railways and in the interests of standardisation and through running one or other of these systems is usually used. The outstanding example of the extension of a 750 V d.c. system to maintain standardisation is the Southern Region of British Rail. What was when commenced a short suburban route now has main lines based upon it which stretch out from London up to and rather over one hundred miles. Theory does win out sometimes nevertheless, the first route of the Milan Metropolitan, 10 miles long and opened 1964, was electrified at 750 V d.c. with third and fourth rails. The second route opened in 1968 (which crosses the first and is physically connected with it) will ultimately be extended deep into the surrounding countryside (serving Gorgonzola of cheese fame), logically uses 1,500 V d.c. with an overhead wire. The heavy current flows associated with low voltage d.c. lead to the use of a third rail to supply 750 V power because of its superior cross-section compared with an overhead wire. The return current to earth is often passed through the running rails, but this practice sometimes results in current leakages from the rails which causes accelerated

cathodic corrosion of near buried metallic structures, quite often structures not belonging to the railway. For this reason an effectively insulated fourth rail is used for the return circuit in many cases. On the Milan Metropolitan route this fourth rail is earthed at two points only and it is a measure of the heavy currents to be handled that the fourth rail is reinforced with aluminium strip on each side of the rail web.

While it can be claimed that industrial frequency electrification is the preferred system today it may not always be so in future. It has been pointed out that upping a d.c. traction voltage to 6,000 V would give an economy similar to that of industrial frequency and the Soviet Union Railways already has a line electrified at 6,000 V d.c. on an extended trial basis. Furthermore, below will be found a mention of an electronic 'chopper' method of feeding d.c. to locomotive traction motors. Should all the locomotives of, say, a 3,000 V d.c. system be equipped with choppers, the insulation difficulties on board the locomotive that at present inhibit the use of a higher voltage would be overcome and there would be no great difficulty in pushing the line voltage up to 6,000 V. Should it be possible to use a rather higher voltage than 6,000 V d.c. this system may become more economical than industrial frequency, although it must be remembered that generally electrification systems cannot be changed overnight to suit the latest and cheapest method of railway electrification. If any great mileage is involved the necessary capital expenditure would be colossal, which is one reason for the survival of the Southern Region 750 V d.c. system mentioned above. Other of the older electrification systems also survive on a considerable scale, as will be seen by examining Table 1.

The table shows that from Switzerland across Germany and north through Sweden as well as in some neighbouring countries, low frequency single phase electrification remains supreme, while a number of other European countries retain either 1,500 V d.c. or 3,000 V d.c. systems. France, Czechoslovakia and the Soviet Union are large enough to have extensive industrial frequency electrification areas while still maintaining the original d.c. electrification elsewhere. A notable country missing from the list is the United States, which for one reason and another has never had a national electrification system and which has anyway since the second world war lost much interest in railway development. The tide may be on the turn just now for the Americans and eventually they may gain modern electric railways. In Europe, a comparatively small place, the existence of the various different electrification systems is becoming an embarrassment, because for operational reasons it is convenient for locomotives and motor-coaches to cross one or more national boundaries during the course of their journeys. In 1964 both the French National Railways and the German Federal Railways acquired locomotives that could run under the wires of four different electrification systems and the Belgian National Railways is about to have locomotives similar to the French design. In all three countries and some others there are a number of locomotive and motor-coach types suitable for working on two, three or four different electrification systems, but such motive power is complicated and expensive

TABLE 1. Railway electrification in selected countries

Country	Former electrification system	Present electrification system
Austria	15,000 V single-phase 16 $\frac{2}{3}$ c/s	15,000 V single-phase 16 $\frac{2}{3}$ c/s
Belgium	3,000 V d.c.	3,000 V d.c.
Canada	—	50,000 V single-phase 60 c/s (proposed)
Chile	3,000 V d.c.	3,000 V d.c.
Czechoslovakia	3,000 V d.c.	25,000 V single-phase 50 c/s
France	1,500 V d.c.	25,000 V single-phase 50 c/s
Germany	15,000 V single-phase 16 $\frac{2}{3}$ c/s	15,000 V single-phase 16 $\frac{2}{3}$ c/s
Hungary	16,000 V single-phase 50 c/s	25,000 V single-phase 50 c/s
Italy	3,000 V d.c.	3,000 V d.c.
Japan	1,500 V d.c.	25,000 V single-phase 60 c/s
Morocco	3,000 V d.c.	3,000 V d.c.
Holland	1,500 V d.c.	1,500 V d.c.
Norway	15,000 V single-phase 16 $\frac{2}{3}$ c/s	15,000 V single-phase 16 $\frac{2}{3}$ c/s
Pakistan	—	25,000 V single-phase 50 c/s
Poland	3,000 V d.c.	3,000 V d.c.
South Africa	3,000 V d.c.	3,000 V d.c.
Soviet Union	3,000 V d.c.	25,000 V single-phase 50 c/s
Spain	1,500 V d.c.	3,000 V d.c.
Sweden	15,000 V single-phase 16 $\frac{2}{3}$ c/s	15,000 V single-phase 16 $\frac{2}{3}$ c/s
Switzerland	15,000 V single-phase 16 $\frac{2}{3}$ c/s	15,000 V single-phase 16 $\frac{2}{3}$ c/s

and has been brought about only because of the lack of standardisation. The existence of all these electrification systems in full use is the excuse for the previous historical pages outlining their development, which in a book called Future Railways may be thought to be inappropriate. Nevertheless, developments will have to take the existence of the various systems into account and will have to be adapted for each of them. It might be added

too that the history is only a summary of the main trends; knowledgeable readers will be aware of many electrification system variations and byways, some of great interest.

ELECTRIC LOCOMOTIVES

In today's orthodox industrial frequency locomotive, say British Rail's class 86, the traction current is collected from the overhead wire by a pantograph, passes through a ultra-rapid circuit breaker to protect the locomotive circuitry from excess current and is fed to a transformer, which drops the voltage from 25,000 to a value suitable for the traction motors. After this the current is rectified from a.c. into d.c. in a solid-state silicon diode rectifier (British Rail was the first to use a solid-state rectifier in motive power experimentally in 1955). It is a property of silicon crystals that they will conduct electricity, but only in one direction. Thus should an alternating current be led to one face of the crystal and a wire to complete the circuit to the other face, the crystal will pass alternations in the supply going in one direction only, the output therefore being direct current. The class 86 locomotive carries four rectifiers, one for each motor, and each of these rectifiers has 96 crystals, known as diodes. The diodes are mounted in capsules screwed into a thick metal plate, for the diodes become warm when carrying current and the plate acts as a heat sink and is cooled by a blast of air. Diodes are the basis of electronic engineering and will be met with in many other railway applications, as well as everywhere else from the humble transistor wireless set upwards.

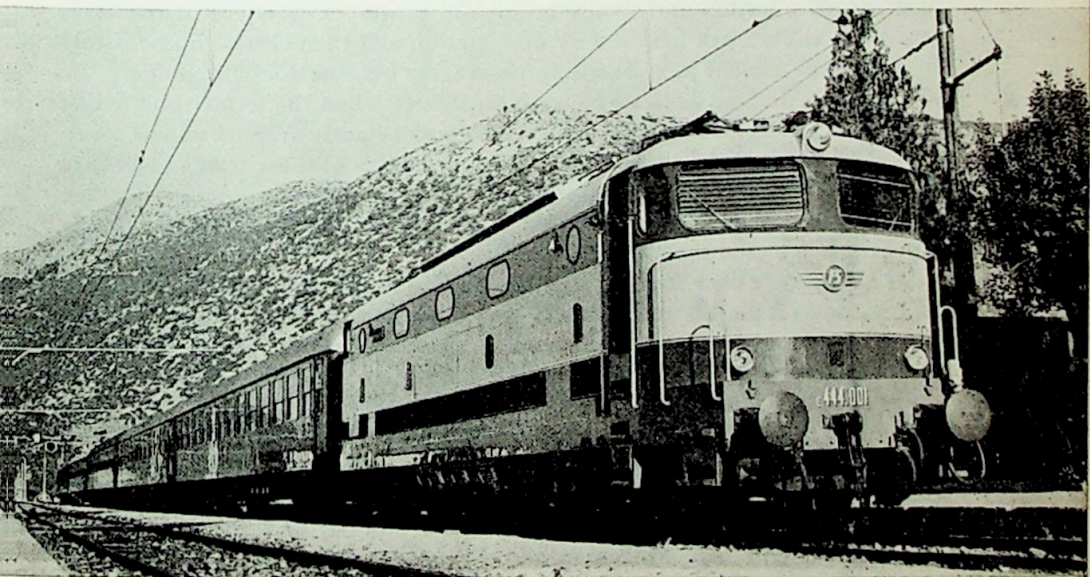
The d.c. current from the rectifiers is passed to the traction motors, which like all traction motors need a high current at starting, which implies low voltage, and a high voltage when running at full speed, which implies a lower current. In the case of the class 86 the maximum motor voltage is 1,200 and the voltage is increased from a low level at starting to this maximum by tapings on the transformer, the first tapping producing a low voltage and so on. There are 38 of these tapings in the class 86 which are selected one by one as the driver turns his controller round. Although not provided on the class 86, in the interests of keeping the control circuitry as simple as possible, it is possible to make traction motors run faster after they have reached maximum voltage by cutting the voltage supplied to part of the motor internal circuitry. This is known as weak field working and when present the driver's controller brings it into action by being pushed still farther round. It should be noted that it is usual on all modern electric locomotives to provide for automatic acceleration, that is running through the various controller positions automatically. The driver can push his controller right round should he wish and the various positions will be run through automatically until the locomotive reaches maximum speed, or until the automatic mechanism catches up with the position the controller has reached.

On direct current railways locomotives normally are not fitted with a transformer and another arrangement to vary the current and voltage applied

to the traction motors is adopted. After passing through the ultra-rapid circuit breaker the current from the overhead wire is led through a bank of resistances (which cut its voltage) to the traction motors, which at starting are wired in series. In series working the current passes through first one motor then the next and so on all down the circuit, each motor then working at a proportion of the voltage applied to the ends of the circuit. To take a modern 3,000 V d.c. locomotive, the version of the E444 class the Italian State Railways built from 1970, this has four traction motors and in full series working each of these motors will work at a maximum voltage of 750, one-quarter of the 3,000 V. Because of the resistances in circuit the starting voltage to the motors is very much less than 750 and the current proportionately higher. The locomotive is accelerated step-by-step by cutting out the resistances one by one, thus raising the voltage at each step, and in the case of the E444 class there are 43 of these resistance steps followed by five weak field steps. This is a greater number of steps than in most locomotives, but the class is designed near the limit of adhesion and sudden changes of the force exerted by the driving wheels on the rails may lead to loss of adhesion and wheel spin; thus the alterations in power exerted are made as small as possible. For the same reason of wheel spin avoidance, the E444 class at starting runs through the five weak field steps in reverse order to provide for the gradual building up of the full starting current. This provision is unusual, perhaps unique, and obviates the normal sudden application of full starting current.

Having reached the limit of series working, the traction motors of the E444 class are then switched to series-parallel working. That is, two motors still in

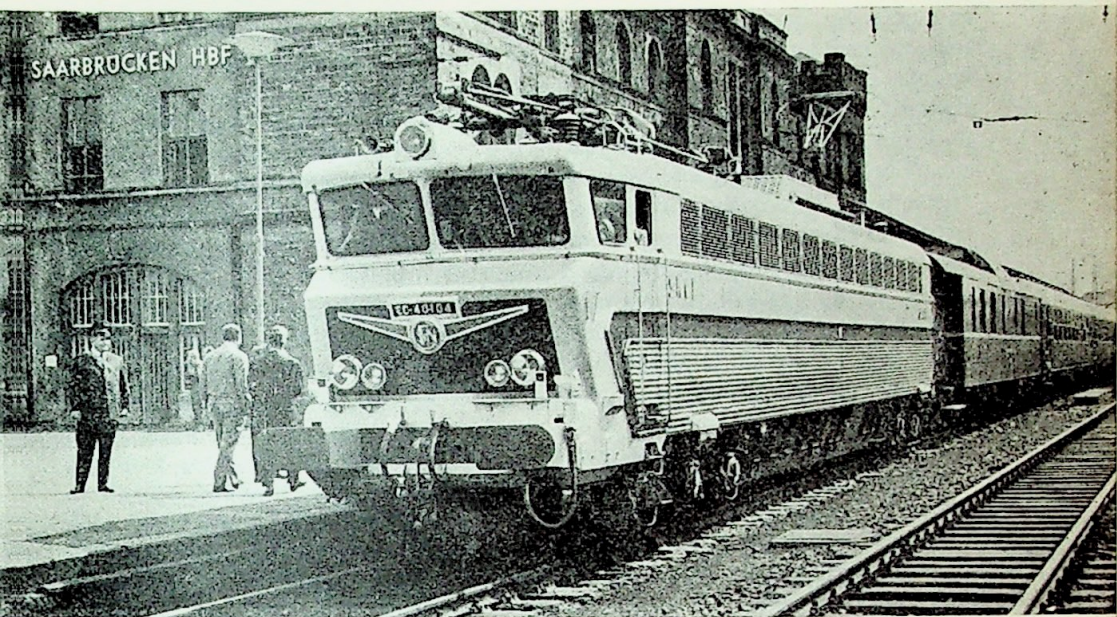
Prototype Italian State Railways 3,000 V d.c. Bo-Bo electric locomotive built 1968, for the E444 class 125 mile/h locomotives built from 1970



series make up a group and the two groups are fed with current at 3,000 V; the motors therefore in this method of working have a maximum voltage of 1,500. Simultaneously with the switching to series-parallel working, 21 resistances are re-inserted into the traction current circuit so that the net effect of all the switching is a very small rise in the voltage applied to the traction motors. The 21 resistances are then cut out one by one as before, until the 1,500 V level is reached, followed by five weak field steps, at which point the locomotive can run at its full speed, which for this class is 125 mile/h. It is to be noted that in the E444 class full parallel working, that is, 3,000 V applied to each of the traction motors direct, is not provided for, because the insulation of 3,000 V motors is difficult in the space available. For this reason the motor voltage is limited to 1,500 and the insulation problems are abated. It will be recalled that the Milan Metropolitan has two operating voltages, 750 V d.c. and 1,500 V d.c. The same rolling stock runs at both voltages; when drawing current at 1,500 V from the overhead wire the 750 V traction motors are permanently connected in pairs in the motor-coaches for series working within each pair, while when picking up 750 V current from the third rail it is possible to run all the motors in full parallel.

The E444 class, like other modern electric locomotives, has automatic acceleration included and the driver's controller merely sets the limit to which this acceleration is to go. The transition from series working to series-parallel working in this class involves the most sophisticated switching circuitry and in fact the current flow to the traction motors is never cut off entirely. It was very different in the old days. When I was young I rode in the 1907 'tube' stock of what is now the Northern Line of London Transport. To change from series to parallel working in the motor-coaches of these trains the driver first shut off power while the train was fully accelerating, then turned a switch and finally re-applied power. The effect in the train was first a violent jerk followed by deceleration and then almost immediately an even more violent jerk. Standing passengers became adept at judging the speed of the train so as to be hanging on tightly when the jerks came, while passengers sitting in the longitudinal seats nonchalantly swayed to and fro in unison. Looking at the crude electrical arrangements of these trains nowadays makes one wonder how any informed passenger plucked up enough courage to use them, yet my father travelled in them every working day for nearly 20 years and I used them a good deal.

The resistance bank used on d.c. locomotives is inclined to be heavy and as an electro-mechanical device calls for maintenance from time to time. Furthermore, when the resistances are in use they become hot and this heat has to be dissipated by air cooling (for cooling see Chapter III), the lost heat representing wasted electric power from the overhead wire. A way of getting round these troubles has arrived in the last few years, the solid-state thyristor 'chopper' which is on the point of coming into general use. The thyristor in conjunction with diodes forms a solid-state switch which is capable of being rapidly closed and opened; for locomotives a number of these switches are used to carry the high loads required. Current is fed to the d.c. motors in



French National Railways four-current Co-Co electric locomotive on the German Federal Railways, CC-40100 class

short bursts by the chopper as the switches close and open and by varying the length of the bursts the voltage supplied to the motors can be altered as desired. While current is flowing a capacitor is charged and this discharges when the current is cut off so that the flow of current to the motors is to all intents and purposes continuous. The rate of switching is controlled by varying the current value of a low voltage reference circuit; this circuit contains the driver's controller and he is thus able to start and accelerate the train. Furthermore, by integrating the signals from another reference circuit whose current values are set by the readings of a speedometer it is possible to mark the driver's controller with speed settings. The driver can then push the controller to the desired speed setting and the locomotive will accelerate the train to that speed and maintain it up hill and down dale, always provided the maximum power of the locomotive will permit it. As there are no resistance steps there is a smooth application of power to the locomotive wheels and adhesion is thereby improved, for faster accelerations and for the haulage of greater loads.

The application of solid-state chopper control on d.c. electrified railways has been regarded with some suspicion because the making and breaking of heavy traction currents is apt to induce unwanted currents in nearby circuits—those used for signalling or telephones, for instance. Electrical induction can be put to good use when required, in transformers, for example. A high voltage current flowing in the transformer primary windings, which are in close proximity to, although quite unconnected with, the secondary windings,

induces a current in the latter. The design of the transformer is such that this induced current is of the required lower voltage. The trouble expected from the d.c. chopper does not arise so much from the bursts of current directed towards the traction motors, but rather on the effect the constant stopping and starting of the current flow has on the current flowing towards the chopper. These disturbance effects, harmonics the engineer calls them, work back through the locomotive circuitry and pass through the pantograph into the overhead contact wire. In signalling, alternating currents and pulsed currents are used to provide different signal indications, so false signals to the train might arise, it is felt, through induced harmonics from the contact wire affecting signalling currents. Sufficient locomotives and motor-coaches have now been in service to show that induced currents from choppers can be guarded against, either by ingenuity in designing locomotive circuits or by altering signalling circuits.

The Japanese National Railways has had chopper locomotives running since 1966 and the English Electric-AEI company in England supplied chopper equipment to the Netherlands Railways for trial in 1967 and equipped the motor-coaches of a pair of two-coach sets in 1970. The Belgian National Railways had a dozen chopper-controlled motor-coaches delivered in 1971-72 and the Stockholm underground railway and in America the new Bay Area Rapid Transit System in San Francisco had similarly controlled motor-coaches during 1972. The Italian State Railways has two of its E444 class locomotives built with chopper control. In Japan the Chiyoda Line of the Teito Rapid Transit Co, Tokyo, was equipped with a complete fleet of chopper-controlled motor-coaches when it opened in 1969. Teito Rapid Transit reports a power saving of 8 per cent compared with a previous resistance-controlled motor-coach fleet on another line, while maintenance costs are reduced and train operation is smoother. A side effect for this underground metropolitan line is a cooler atmosphere in the tunnels, because air heated after cooling the resistance banks is no longer discharged into them. Despite worries about interference with non-traction electric circuits it is evident that chopper control has arrived on d.c. railways.

British Rail used thyristors in a different manner for its 74 class locomotives for 750 V d.c. in 1968. For various reasons (the locomotives are rebuilds of a previous design; a low-power diesel engine is installed for working on non-electrified lines and so on) the voltage of the traction motor current is controlled by the buck-and-boost method. That is, a constant supplementary current is fed into the traction motor current whose voltage is varied, at first negative to the traction voltage and then gradually diminishing towards zero voltage followed by a positive phase gradually increasing. The combined currents supplied to the motor are thus low voltage first, when one voltage is deducted from the other, and high afterwards when the two voltages are added together. In the ordinary way the buck-and-boost method is of no great interest to the d.c. locomotive designer as the control of current by resistance banks is more economic, but in this case thyristor voltage variation of the supplementary current coupled with the other factors made the method

desirable. In theory when using thyristors to control the supplementary voltage the current flowing to the traction motors is infinitely variable in voltage, but in practice these locomotives had to run in multiple with resistance-controlled motor-coaches and to run with a diesel engine providing current. To meet these conditions the driver's controller works in steps in a similar way to the other motive power and the thyristors also regulate in steps to conform. For this reason the improved adhesion effect is not attained for these locomotives.

When the 74 class locomotives were first in traffic they gained a name for unreliability, due, it must be said, to trouble with the electronic circuitry, the troubles illustrating the unforeseen happenings which occur when fresh technology is adapted to railway uses. The makers of the electronics were warned that railway conditions would be hard going for their equipment, but the makers were armed with fall-out knowledge from such tough environments as moon rockets and were confident that they could meet requirements. No doubt other railways also have suffered from these unforeseen happenings, some of them deceptively simple. For example, to secure a miniature electronic circuit wire to a metal surface a small blob of solder is almost universally used. The solder holds the end of the wire firmly but the wire outside the solder is free to vibrate and on a locomotive it was vibrated for long periods of time. Eventually the metal of the wire just at the point where it entered the solder became fatigued, and then one of the stronger shocks to which locomotives are subject led to the wire breaking at that point. Sometimes the breaking of an electrical circuit in this manner meant that the whole locomotive came to a stand. In short, what was good enough for a moon rocket could not survive the rough-and-tumble of Clapham Junction and Waterloo. The trouble was overcome by providing a post on the metal surface round which the wire was twisted and another bit of railway technique was thus added to the store of engineering knowledge.

Turning now to single-phase low frequency electrified railways, the single-phase traction motor is similar in design and functioning to the d.c. motor, such modifications as there are for single-phase current insisting on the low frequency and not allowing an operating voltage as high as 1,000 V. Attempts have been made to design industrial frequency traction motors, which have worked up to a point but remain unsatisfactory and less flexible in performance than other types. Single-phase low frequency locomotives carry a transformer to reduce the overhead wire voltage to that required for the traction motors. The driver's controller selectsappings on the transformer, first for low voltage and then for increasing voltages. In a typical instance, the Swiss Federal Railways class Ae 4/7 (an older type dating from 1927), there are 21 of theseappings from the secondary windings of the transformer. It should be remarked that switching transformerappings on and off so glibly mentioned here (and similarly switching resistances out of circuit in d.c. locomotives) is by no means so easy as flicking at an ordinary domestic light switch. This is because of the high voltages and currents being handled, up to and over 1,000 amperes. To avoid arcing and other troubles, all sorts of

auxiliary switches, resistances and other design features are used. The Swiss locomotive mentioned above had transformer tapings on the secondary circuit of the transformer, but modern practice initiated in Switzerland places the tapings on the primary windings of the transformer. The voltage may be high, 15,000 V, but the current flow is correspondingly low. Thus one of the latest locomotive types of the Swiss Federal Railways, the Ae 4/4^{II} class, has 32 transformer tapings, all on the primary side.

In 1950 two locomotives were built in the United States, which were acquired later by the then Pennsylvania Railroad, that broke away from traditional low frequency practice (in this case the frequency was 25 c/s) and were equipped with d.c. traction motors. Current was supplied by mercury-arc rectifiers placed on the overhead line side of the transformer. These rectifiers were of a special type known as ignitrons, the description of which need not concern us here. Control of the d.c. current was exercised partly in the ignitrons and partly by tapings on the secondary side of the transformer. The Pennsylvania Railroad had 66 more locomotives similarly controlled, the E44 class of 1962-63. The Swedish State Railways substituted d.c. traction motors for single-phase motors in two prototype Rb1 class locomotives built in 1962. In this case the single-phase low frequency supply was rectified by a solid-state silicon diode rectifier placed in circuit after the transformer. On the whole the Swedes found no great advantage or economy by this step. But they took one step further and added chopper control of the motor current (or more properly thyristor control, for the rectifier and chopper circuitry was in effect merged) which had decided advantages. In particular the adhesion of locomotives was increased so much that they could regularly haul greater loads. A trial motor coach was rebuilt with thyristor control in 1964 and one of the Rb1 class locomotives in 1965. Since 1967 nearly one hundred d.c. motored and thyristor-controlled locomotives have gone into service on the Swedish State Railways (Rc1, Rc2 and Rc3 classes) as well as over one hundred X1 class motor-coaches.

The Swedish electrical engineering firm Allmänna Svenska Elektriska AB (ASEA) was the builder of the electrical equipment and the same firm supplied equipment for 30 conventional industrial frequency electric locomotives for the Roumanian State Railways (class 060EA). It persuaded the Roumanians to have one similar but thyristor-controlled locomotive as well in 1967 (class 060EB). Canadian Pacific Rail has been seeking the assistance of ASEA and it seems likely that the locomotives for the proposed western Canada electrification will be thyristor-controlled also. The German Federal Railway after trials started taking delivery of thyristor-equipped motor-coaches in 1970 for local service (ET420 class) and a forthcoming high-speed version will be similar. Finally the French National Railways has acquired thyristor-controlled type locomotives for its 25,000 V, 50 c/s, lines, the BB15000 class of 1970, and French and Belgian makers supplied thyristor locomotives to South Korea in 1972.

Transmitting the rotary motion of the electric motor to the axle presents its problems as ideally the weight of the motor should be sprung and the axle is

necessarily unsprung; thus there would be relative movements between the two. The traditional method for the transmission of the drive is cheap and simple and involves the nose-suspension of the traction motor. That is, the motor (with the rotor parallel to the axle) is attached to the sprung frame on one side and has the other side (the nose) resting on a bearing on the unsprung axle. A pinion on the motor rotor engages with an axle-mounted gear wheel and spring movement of the motor merely causes this pinion to move a little round the gear wheel. This arrangement is used on many of the world's electric locomotives and on still more of the diesel-electric locomotives. The arrangement has the disadvantage that it increases the unsprung weight of the locomotive resting on the track and at high speeds this increases track maintenance costs, as has been found with the nose-suspended motors fitted to British Rail's class 86 electric locomotives. In British Rail's class 87 locomotives, which should be in traffic by the end of 1972, the motors will be fully-sprung and their rotors will be hollow. Through the hollow rotor will pass a cardan shaft articulated at both ends. One end of the cardan shaft will be fastened to the rotor and the other will be attached to the pinion engaged with the axle-mounted gear wheel. As the motor bounces up and down on its springs the relative movement between the rotor and the pinion will be taken up by the cardan shaft and its articulated joints. This arrangement has been used on locomotives built in Sweden since 1962 (notably the Rb1, Rc1, Rc2 and Rc3 classes) and on 195 locomotives of Swedish design for industrial frequency electrified lines now being delivered to the Yugoslav Railways (441 class).

Elsewhere in Europe outside Great Britain railways have long favoured fully-sprung traction motors and a great many ingenious methods have been devised to transmit the rotary drive of the motor to the driving wheels of the locomotive, most of which still remain in use. A common method is called the quill drive. In one version of this (fitted to the Italian State Railways E428 class) six leaf springs are symmetrically disposed in the wheel in place of some of the spokes. The nose-suspended traction motors (a twin motor in this case) drives a hollow axle on which it is suspended, the hollow axle surrounding the main axle connecting the wheels. Arms projecting from each end of the hollow axle (the quills) are fastened to the springs in the wheels in such a manner that each fastening can slide up and down the spring leaf. All the springs in the wheels transmit the rotation of the traction motors. The two springs that happen to be horizontal at any moment take the weight of the hollow axle and part of the weight of the motor that rests on the hollow axle. The springing of the hollow axle on the horizontal springs is accommodated by the quills sliding up or down the non-horizontal springs in the wheel. Another method of transmitting rotary motion from a hollow axle to wheels is by a system of rubber-sprung and jointed levers, the rubber and levers accommodating the springing movements. This method is used on the Italian State Railways E444 class locomotive and is shown in Figure 1, page 35. Yet another arrangement is popular for motor-coaches on metropolitan railways. In this the sprung traction motors are arranged in the bogies at right-angles to the

axles. The drive from a rotor is through an articulated cardan shaft and a differential in the manner of a motor-car.

In recent years in France and in some other countries monomotor bogies have been used. In these a large sprung traction motor is fitted to each bogie (either four-wheel or six-wheel) and drives the axles through a train of gears, the springing between the motor and the axles being taken up in the gear train. Such monomotor bogies are fitted to many modern French locomotives, classes BB8500, CC6500, BB15000 and others, as well as to diesel-electric locomotive classes BB67000 and CC72000. The monomotor arrangement lends itself to changing the gear ratio while the locomotive is stationary, to make it suitable for either freight or passenger trains. Previously it sometimes happened that two otherwise identical locomotive types would have to be provided, one with a high gear ratio and the other with a low, as examples the Italian State Railways E645 and E646 classes. Taking the weight of the traction motors out of the bogies altogether and placing them on the body reduces track maintenance cost as it receives fewer shocks from the wheels. The latest method of doing this is to sling the traction motors at right-angles beneath the body and drive two axles of an adjacent bogie through a cardan shaft from each motor. The first use of such an arrangement for high power is in the Italian State Railways 155 mile/h prototype tilting body motor-coach train set. The traction motors tilt with the body and the cardan shafts have to deal with this movement as well as the movements of the bogie relative to the body. The Czechoslovakian State Railways is designing a similar cardan shaft-driven 125 mile/h locomotive, for which it hopes to develop an epicyclic gear box and friction clutch to allow the motors to be changed from a high to a low gear ratio while the locomotive accelerates.

DIESEL LOCOMOTIVES

The first commercial locomotive fitted with a diesel engine was apparently a small narrow-gauge product of Richard Hornsby & Co Ltd in 1896. As a historical curiosity it may be noted that this firm was in competition with the German firm which employed Rudolph Diesel, who gave his name to the engine he developed. Hence Hornsby products were known as oil engines, both by them and their successors Ruston & Hornsby, for seventy years after 1896 and their locomotives were called oil engine locomotives. The 1896 locomotive had a mechanical gear box transmission and such mechanical transmission is still used for small locomotives up to about 150 hp. With a fluid coupling interposed between the gear box and the engine to protect the latter from the ruder shocks from gear box and wheels the horsepower can go up to about 450 and such transmissions are much used for diesel railcars. The fluid coupling consists essentially of an engine-driven bladed disc in an oil bath. Closely opposed to the first disc is a similar disc connected to the gear box and thus the wheels, the oil that is spun round by the rotation of the engine-driven disc causing the latter disc to turn as well and thus transmit the rotary motion. The problem in the diesel locomotive is to convert the relatively high speed and

regular rotary motion of the diesel engine to the slow and variable speed required by the locomotive driving wheels. To cope with this electrical transmissions were developed, dealt with below, and then hydraulic transmissions. The first hydraulic transmission was in the hydrostatic form and a number of locomotives were built from 1924. An engine-driven pump circulated oil round a circuit and in the circuit was another pump (usually of a similar swash type to the first) which was worked in reverse by the flowing oil and thus drove the locomotive wheels. Hydrostatic locomotives had little success at first because of the high pressure developed in the oil circuit, up to 4,000 lbf/in², but after the second world war hydrostatic diesel shunting locomotives had a vogue on the Italian State Railways and considerable numbers of some successful designs were built up to 500 hp. The increasing efficiency of the hydrokinetic shunter now limits the economic maximum horsepower to under 200.

The first diesel-electric was a little railcar built for the Swedish State Railways in 1912 and quite a number of small railcars and locomotives were built by ASEA with an Atlas engine in Sweden during the next 12 years. In 1924 diesel-electric locomotives were built in a number of other countries for the first time, including the United States, and ten years later the diesel-electric locomotive was developed sufficiently to start its motive power sweep over the non-electrified railways of the world, as well as taking over from electrified locomotives in a number of cases in the United States. In today's orthodox diesel-electric locomotive the diesel engine drives a generator which provides d.c. for the d.c. traction motors. Primary control of the locomotive is by raising the speed of the diesel engine, for as the generator turns faster it produces a greater voltage. Unfortunately the power production characteristics of the diesel engine and the generator do not match; the latter at most speeds can absorb more energy than the diesel engine can produce, so the driver's controller not only alters the engine's speed by selecting different fuel injection rates, it also simultaneously alters the circuitry of the generator to match the selected engine speed. Secondary control can also be provided by getting the driver's controller to switch the traction motors from series to parallel working or by bringing one or more weak field steps into play.

An interesting example of the flexibility of the diesel-electric locomotive occurs on the Southern Region of British Rail. Here diesel-electric locomotives are arranged so that they can pick up current from the 750 V third rail for their traction motors and run with the diesel engine shut down if desired. Furthermore, in either the diesel-powered or third-rail powered traction mode the locomotive can be controlled from the motor-coach driving cab of straight electric traction multiple-unit train sets. In theory, carrying a dead diesel engine about on an electrically-driven locomotive is wasteful, but the practice suits the operating arrangements on this system. Most diesel engine manufacturers produce engines suitable for railway use, that is the engine is so designed it will fit into the confines of a railway body, and there is a wide range of horsepower available up to 6,300, although this latter engine has yet to be built into a locomotive. Two engines are often installed in the more

powerful locomotives and in the case of railcars that are designed to run in multiple-unit trains the driver simultaneously controls half-a-dozen or more engines. Apart from physical dimensions diesel engine makes have been perfected over the years for reliability and maintenance costs often guide railway administrations in the selection of a particular type. Successful diesel engines become international in character; thus the Swiss Sulzer type is manufactured under licence in France, Great Britain, Roumania and so on, the French Pielstick engine is made in Sweden, Czechoslovakia and Hungary, the American GM engine in Sweden and Australia, the British Paxman engine in Italy and so forth. Neither the list for the various countries in which individual engines are manufactured nor the list of engine types are exhaustive.

About 1930 the hydrokinetic version of hydraulic transmission was developed for railway use—the Lysholm-Smith transmission in Sweden and the Voith transmission in Germany. In principle the transmissions work like a fluid coupling, two opposed discs in an oil bath, one of the discs driven by the diesel engine and the other driven by the oil whirled round by the first disc and being coupled to the locomotive driving wheels. The oil whirled round by the blades of the first disc is directed to hit the blades of the second output disc twice and by this means a high engine rotary speed becomes a lower output rotary speed with minimum losses. As the engine speed is increased the locomotive accelerates. The output side of this converter hydraulic transmission is geared down to a suitable speed for the driving wheels and cardan shafts connect this gear box with one or more locomotive axles. An advantage of this diesel-hydraulic transmission when it was perfected was that the locomotive as a whole was considerably lighter than a comparable diesel-electric locomotive. A small shunting locomotive was fitted first with the Voith transmission in 1932 and in 1934 the German State Railways took delivery of the first main line locomotive, the V160 class. The Lysholm-Smith transmission had considerable application in railcars during the 1930s and later. A single hydraulic converter can only deal with a limited range of locomotive speeds and to meet the required higher speeds a gear box was added to the Lysholm-Smith transmission for them. At higher speeds the stresses and strains on a gear box for locomotive use are lessened so that this was feasible. After the second world war other hydro-mechanical transmissions of this sort were devised, the Mekydro in Germany and the Ganz in Hungary among them. Voith did not go in for a gear box and to meet the demand for higher speeds it added an additional fixed hydraulic transmission stage and even another. These additional transmissions are brought into play by pumping oil into them as required, or draining the oil out of them when not needed. The driver's control as well as increasing the speed of the diesel engine also brings in the automatic gear boxes and the additional hydraulic stages as required.

Except for Ganz the hydraulic transmissions mentioned are manufactured under licence abroad in the same manner as diesel engines, including the Swedish SRM type which comprises several hydraulic transmission stages in

the same manner as the Voith. Many railways have had diesel-hydraulic locomotives, but they have never really caught on for main line use. The Western Region of British Rail used a few hundred in the 1960s and early in the period the mechanical engineer in charge could claim that for comparable horsepower his diesel-hydraulics at about 80 tons could haul an extra coach compared with diesel-electric locomotives weighing about 110 tons or so. Since that time the diesel-electric locomotive unit weight per horsepower has steadily dropped, while the diesel-hydraulic locomotive has shown rather greater maintenance costs. Only the German Federal Railway remains an extensive user of diesel-hydraulic locomotives and even there there are signs of second thoughts, so it may be that the main line diesel-hydraulic is on its way out. For shunting locomotives the hydraulic transmissions have been more successful, helped by the fact that the reduction gears between the hydraulic transmission and the driving wheels can be arranged to give two pre-selected running speeds, one high for maximum haulage capacity on heavy shunting duties and one lower for use when running on the open line.

One of the reasons why the unit weight per horsepower of diesel-electric locomotives has dropped is the substitution of an alternator in place of a dynamo as the generator of the locomotive, that is the generator supplies three-phase a.c. instead of d.c. The three-phase is rectified for the d.c. motors in a solid-state silicon diode rectifier. The alternator is simpler to manufacture than a dynamo, it does not weigh so much as the latter and it does not possess a commutator, which in turn reduces maintenance. A generator as such produces a.c. and a commutator is a device mounted on the rotor shaft from which stationary carbon block brushes are able to pick up direct current (originally generator brushes were made up of multiple strands of braided small diameter copper wire which resembled a brush). The contact carbon blocks wear in use and require maintenance, the device limits the speed of the generator and sometimes there is a short-circuit, known as commutator flashover. The d.c. motor also has a commutator, which works in a reverse manner to that of the dynamo, and thus getting rid of one or both of these commutators can lead to decreased maintenance. Diesel-electric alternator locomotives were first built in France from 1965, the first two having two engines, No. CC70001-70002. These were followed by the single-engined 72000 class in 1966, which type was also built for the Moroccan Railways in 1967. The British manufacturer Brush Electrical Engineering produced a prototype locomotive called *Kestrel* with an alternator in 1968, which ran trials on British Rail before being sold to Russia in 1971. Other railways have diesel-alternator locomotives in service and British Rail's 41 class which first appeared in 1972 is similar.

Solid-state technology had an application in the diesel locomotive when Brush Electrical Engineering tried out a current inverter in 1965. The prototype locomotive *Hawk* had a diesel engine and an alternator which supplied a solid-state rectifier, the latter supplying d.c. to the current inverter. The output of the current inverter was three-phase a.c., the frequency of which could be smoothly and continuously altered as required. The locomotive

was equipped with asynchronous traction motors, the speed of which varied with the frequency of the current supplied to them, thus allowing control of the locomotive running speed. The current inverter was based on d.c. fed solid-state thyristor and silicon diode switches, which switched continuously from positive to negative polarity. Three sets of these switches were fed with d.c. and thus there were three output wires for three-phase supply, the switching action simulating a.c. As with chopper control of d.c. the value of a reference current controlled by the driver determined the rate of the switching action and thus the frequency of the three-phase a.c. output and in turn the speed of the locomotive. It will be remembered that at the beginning of this chapter an account was given of three-phase electric traction championed by the Swiss and Kálmán Kandó the Hungarian at the turn of the century, Kálmán Kandó indeed going on to apply three-phase asynchronous traction motors to locomotives fed from an industrial frequency overhead line. These were attempts to put the simplicity of the asynchronous traction motor to use on the railway (among other things no commutators) and the *Hawk* was yet another endeavour to the same end. Unfortunately the locomotive was not a success, for in the engineer's phrase the current inverter suffered from 'instability'—it may be presumed in other words that induced currents and harmonics in the internal circuitry did not allow the inverter to function as planned. Perhaps the idea was ahead of the technology of the time.

The same year, 1965, that saw the abortive trial of *Hawk* the German locomotive building industry foresaw problems ahead. Its home market was being supplied with diesel-hydraulic locomotives, but overseas customers were turning away from the diesel-hydraulic and demanding diesel-electric locomotives instead, which trade rivals were well-equipped to supply. So two firms, Rheinstahl-Henschel and Brown Boveri & Co of Mannheim, set themselves to evolve a standard export diesel-electric locomotive in 1965. The locomotive was to be suitable for the metre gauge and upwards and have a maximum axle load of 12.5 tons for the metre gauge and rather higher for wider gauges. It went almost without saying that the most advanced technology possible was to be incorporated. Six years of research and development followed before the prototype locomotive took to the rails in 1971. This prototype is for the standard gauge with a 2,500 hp engine which drives an alternator, the three-phase a.c. output of which is passed to a solid-state rectifier. The d.c. output of the rectifier is presented to a solid-state current inverter (which functions as the British attempt described above) and the inverter in turn feeds continuously variable frequency three-phase a.c. current to asynchronous traction motors nose-suspended on each of the six locomotive axles. The solid-state current inverter has continued to function satisfactorily during a year of trial running on the German Federal Railway and as this is being written in 1972 the sales department of Rheinstahl-Henschel is mounting a sustained publicity campaign to sell the new locomotive type to the railways of the world. It may be wondered, if the generator produces three-phase a.c., why this is not fed direct to the three-phase a.c. asynchronous traction motors. This was looked into during development and it was deter-

mined that the control of current with this arrangement would be a little more expensive than the method adopted, and the locomotive would not be quite so flexible in traffic.

Much of the development work was devoted to the design and testing of a suitable current inverter, but nevertheless the locomotive power plant was treated as a whole. Thus the diesel engine is run at 15 different outputs while the current inverter has a continuously variable output from 0.4 c/s at starting to about 125 c/s. If the two outputs are plotted on paper similar shaped curves result, in other words the current inverter output is matched to the engine output. The engine revolutions and frequency output of the current inverter must be closely related to the rate the locomotive wheels are turning and to ensure this an electronic revolution counter working against a toothed wheel fixed inside one of the locomotive driving wheels is fitted. As each traction motor is fed with current of the same frequency individual axles cannot start spinning and advantage is taken of this feature to design the locomotive very close to adhesion limits, the current inverter's smooth and stepless transmission of power helping in this good adhesion characteristic. It is perfectly possible to install so much power in a locomotive that the wheels spin when it is applied and part of the designer's task is to ensure that the power applied to the wheels is less than the limit of adhesion above which they will spin. In the German locomotive it is possible for all the wheels to spin simultaneously in poor adhesion conditions, the circuitry applying power then giving rise to a rapid acceleration. An electronic device detects any such rapid accelerations and if detected the power is automatically reduced to allow the locomotive a chance to 'regain its feet'. Unlike other traction motors it is a feature of the asynchronous motor that full starting current can be applied to it indefinitely, which means that the driver can push his controller round and then release the brakes; as the brakes come off the train starts. More importantly when the traction motor is being used for electrical braking (see Chapter Three) this feature allows the train to be braked to a halt.

It will be appreciated that all commutators and their associated troubles have been eliminated and that as far as possible all the circuitry is solid-state, which eliminates much other maintenance work. Should the solid-state circuitry fail the offending part is unplugged and a spare circuitry box plugged in. The locomotive is driven by a single controller, which when turned in one direction causes the locomotive to accelerate and when turned in the other applies the electrical brake. It is also possible to switch to various desired running speeds, which with the controller in the appropriate position will be attained by the locomotive and held as long as desired without any further adjustment of the controls, in spite of gradients up or down. Some space has been devoted to describing the various features of this German prototype locomotive here, for it appears to be a decisive step along the road to more efficient and cheaper motive power. In principle there is no reason why current inverters should not be applied to electric locomotives also to make the advantages of the asynchronous traction motor available to them as well. The current inverter requires d.c. for operation but d.c. is already being made

available for d.c. traction motors in locomotives drawing current from $16\frac{2}{3}$ c/s and 50 c/s overhead wires while with d.c. overhead wires there should be no difficulty. The Americans too are interested in current inverters and an experimental motor-coach went into service on the 600 V d.c. third rail line of the Cleveland Transit System, Ohio, in 1969. No doubt design difficulties and disappointments with solid-state circuitry lie in the future (there are complications and problems that have not been hinted at) while cost may give prospective users pause, although cost may come down once such solid-state circuits are widely applied. Nevertheless the great advantages of more haulage power from a given size of locomotive, less maintenance and simplicity of control are worth paying for.

GAS TURBINE LOCOMOTIVES

The gas turbine as a prime mover was first installed in a small Swedish trial locomotive in 1934, which was followed by a larger Swiss locomotive in 1941. After the second world war other countries tried large locomotives, the United States in 1948, Great Britain from 1950 (three, one of them Swiss-built), France from 1952 (three), Sweden again from 1955 (three), Czechoslovakia in 1958 (one) and the Soviet Union from 1959 (two). For the most part they worked very well, but they all ran into the same snag, the gas turbine is only efficient at one speed of rotation. This necessarily has to be at or near maximum output and most railway journeys only call for maximum output from the locomotive prime mover for a very small part of the time. A gas turbine operating below its designed speed of rotation becomes very heavy on fuel and the whole operation is not then economic. Only the Union Pacific Railroad in the United States (which had the first gas turbine locomotive built there in 1948) has gone ahead with this form of motive power and by 1961 had a fleet of 56 units, all with electric transmission on the lines of a diesel-electric locomotive. It is to be supposed that the long gradients up which this line works trains in the Rockies and in other mountain ranges call for the gas turbine to operate for long periods at its designed speed, while when descending the same gradients it can idle if not be shut down altogether.

The gas turbine has advantages over the diesel engine as a prime mover; for a given horsepower it occupies less space and weighs much less. When high-speed railcar trains were proposed in the United States to run at 100 mile/h these qualities were appreciated and gas turbines were selected as the prime movers for the trains, an additional factor being that sustained bursts of high speed would allow the gas turbine to run at its designed output more often. Some trains were built from 1964 which were named Turbotrains and put on the New York-Boston run and as well appeared in Canada for the Montreal-Toronto route. For one reason or another they were not too successful. The French were next with four-coach railcar sets in 1970, class XB4801 and now renumbered T1001. These have a gas turbine at one end and a diesel engine at the other and are booked to run up to 100 mile/h on the Paris-Caen route. During 1972 two four-coach experimental trains with a gas turbine at each

end were built, one with an electric transmission and the other with a hydraulic, TGV 001 and RTG 01 respectively. These have a designed maximum speed of 185 mile/h and similar five-coach sets are on order for ordinary service with a lesser maximum speed. During 1972 as well the Japanese National Railways acquired an experimental gas turbine railcar set and the prototype British Rail Advanced Passenger Train will have a gas turbine-electric transmission.

The power of electric locomotives and motor-coaches is normally expressed in kilowatts and if it is desired to convert these units to horsepower it is necessary to multiply by 1.34. Except for three-phase locomotives with asynchronous motors the traction motors become hot during operation, as do other electrical units such as rectifiers and transformers, and all are cooled by air blasts from fans and blowers. For this reason it is normal to quote two power ratings for electric locomotives, the first for continuous operation and the second for operation for a period not exceeding one hour. After one hour the traction motors would become too hot to run further without a rest or a period of operation at less power. The hourly rating is of course greater than the continuous rating and both are normally the sum of the ratings for each traction motor. On occasion an even higher rating is given to a locomotive for operation during 'a short period', the length of the period rarely being specified. As an example the British Rail class 86 locomotive has a continuous rating of 2,700 kW and can produce 4,470 kW for a short period, the equivalent ratings being 3,600 hp and 6,000 hp.

Power ratings for diesel locomotives and for gas turbine locomotives are quoted in terms of the horsepower of their prime mover. It must therefore be realised that to compare an electric locomotive with a 3,300 hp hourly rating with a diesel-electric locomotive of 3,300 hp is not to compare like with like. The electric locomotive power rating is based on those of the traction motors next to the wheels; the diesel locomotive rating is that of the diesel engine, which apart from moving the locomotive and train along the rails must also supply power for the locomotive auxiliaries. The auxiliaries include air cooling fans and blowers, heating and lighting apparatus, braking air compressors and quite often power for heating the whole train and even supplying it with air conditioning. A deduction of 10 to 20 per cent has to be made from the nominal horsepower of diesel locomotives before they can be fairly compared with an electric locomotive.

To sum up this chapter the motive power contributions towards more economical transport are set out here. Electrification of railways for some time to come will be at industrial frequency and probably at 25,000 V, although higher voltages offer advantages which may be taken where possible. There will be a tendency to convert railways electrified on other systems to the cheaper industrial frequency system. It will continue to be cheaper to electrify short metropolitan railways at 750 V d.c. Electric motive power will increasingly incorporate solid-state circuitry wherever possible, to allow simplicity of locomotive control and improved adhesion (and thus greater haulage capacity), and solid-state circuitry will also allow the lesser weight

and freedom from maintenance of the asynchronous electric motor to be applied to both locomotives and motor-coaches. A detail advantage of the asynchronous traction motor is that its light weight may make nose-suspension possible when applied to high-speed units, thus avoiding the complication and expense of fully sprung traction motors. Diesel locomotives will use an alternator to generate current and thereafter follow the electric locomotive practice set out above. There will be a limited use for the gas turbine as a prime mover, probably for high speeds over suitable portions of secondary routes, for main lines suitable for high speeds are likely to be electrified. As improvements in technology bring about a fall in the overall cost of electric railways it will be possible to electrify railways carrying smaller flows of traffic with the consequent restriction in use of one of the diesel and gas turbine motive power modes.

CHAPTER THREE

Motive power detail and rolling stock

In this chapter some description is given of the problems that have to be solved to enable locomotives to run safely along the rails and the various auxiliaries are also covered. Where the locomotive matters are common to rolling stock it is noted and mention is made of purely rolling stock problems.

Considered solely as a load carrying vehicle a locomotive must carry 30, 40 or even 50 tons of apparatus in its body or mounted on its bogies. In addition to the normal braking forces, traction forces must be transmitted between its bogies and its body. Locomotives are normally carried on two, or sometimes three, bogies and to ensure suitably smooth carriage of the load the bogies must be sprung and the bodies sprung in relation to the bogies. Starting at the rail, the wheelsets (that is the wheels and axles together) must be carried in axleboxes that are allowed a little sideways movement relative to the bogie frame and that must be sprung from the frame for vertical movements, known as primary springing. The bogie must be able to follow curves and traditionally this has been effected by a central pivot and a bearing round it supplemented by slide bearings on the sides of the bogie to take care of body lurches and restrain bogie movements. In modern practice additional springing (secondary springing) is provided between the body and the bogie and some provision is made for sideways movements between the two to accommodate body lurches. The total assembly, known as the suspension, must take account of two sprung vertical movements, two sprung sideways movements and twisting of the bogie to follow curves, all the movements occurring individually or in combination up to all occurring simultaneously. The problem is further complicated as the driven wheels must pull the body and bogies along, or alternatively hold them back when the brakes are applied. The total weight of the locomotive also has an effect and in practice almost every locomotive type has a different design of suspension, if only to deal with the varying weights between types.

As there is no such thing as a standard or typical locomotive suspension and as radically different solutions have been tried at one time or another, it is here proposed merely to describe one modern suspension to show how the problems have been met. The locomotive type selected is the Italian State Railways class E444 carried on two four-wheel bogies. A drawing of one of

these bogies is shown in Figure 1, page 35. The axles of the bogie are carried in roller-bearing axleboxes and the latter have brackets at the base on which the bogie frame rests through a pair of primary suspension helical coil springs, one on each side of the axlebox. Also mounted on the bracket are vertical tubes which rise inside the coil springs and inside the tubes in turn work plungers attached to the bogie frame. The greater part of the body of each plunger is made of elastomer (the term elastomer covers both rubber and plastics with rubber-like qualities), the elastomer producing greater friction when working against steel than steel against steel. The arrangement thus acts as a damper for the coil springs, ironing out small movements in them, and in addition it transmits traction and braking forces. The elastomer also allows some sideways movement of the axleboxes, the coil springs permitting the movement. Indeed, in some designs the coil springs themselves are arranged to cope with some sideways movement on their own apart from their major purpose of dealing with vertical movements. The two vertical rods to be seen outside the coil springs on each side are merely guards that prevent the axlebox moving too far in horizontal planes.

The locomotive body rests on the tops of two secondary suspension springs, the helical coil springs seen in the centre of the bogie. The bottoms of the springs are supported by a bracket which is supported in turn by a swing link, that is a nearly vertical arm with a bearing at each end which can move sideways in relation to the locomotive. The top bearing of the swing link is attached to a beam lying across the bogie frames, the top bearing of the similar swing link on the other side of the locomotive being attached to the beam at its other end. The swing links slope inwards towards the locomotive centre; thus should the locomotive body move sideways in relation to the bogie or vice versa one swing link will become vertical, or attempt to become vertical, and gravity will then restore the centre position. The beam is carried by slides on the bogie frame (steel and elastomer slide faces give the required friction behaviour) and its fore and aft movements are restricted by rubber-sprung articulated arms connecting it with the body at each end, the arm at one end of the beam lying forward and at the other lying aft. From this description it will be seen that there is no bogie pivot and that the secondary suspension has no provision for taking the traction and braking forces between bogie and body. These are transmitted from the bogie to the body by tensioned steel wire ropes, which run from the bogie centre point, and from low down near rail level, fore and aft to brackets on the locomotive body. The locomotive rides well at high speed and the suspension design is regarded as very satisfactory. It will be noticed that rubber and other elastomers are used in the suspension, which is a modern trend and indeed in other suspensions elastomers feature much more widely. Axlebox primary springing now is carried out often completely by elastomers, particularly on metropolitan railways. London Transport used these Metalastik springs for the axleboxes in all stock built in recent years. Steel plates separate successive layers of elastomer in this springing, the layers being arranged in shear at an angle of about 45° between axlebox and bogie frame.

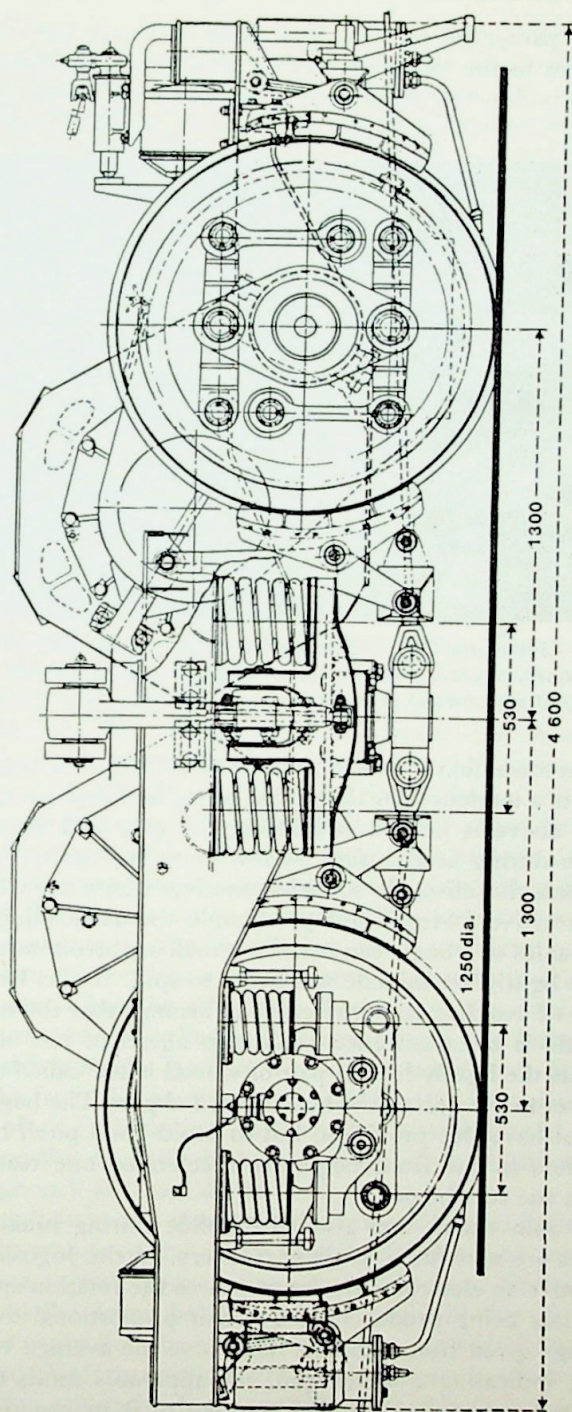
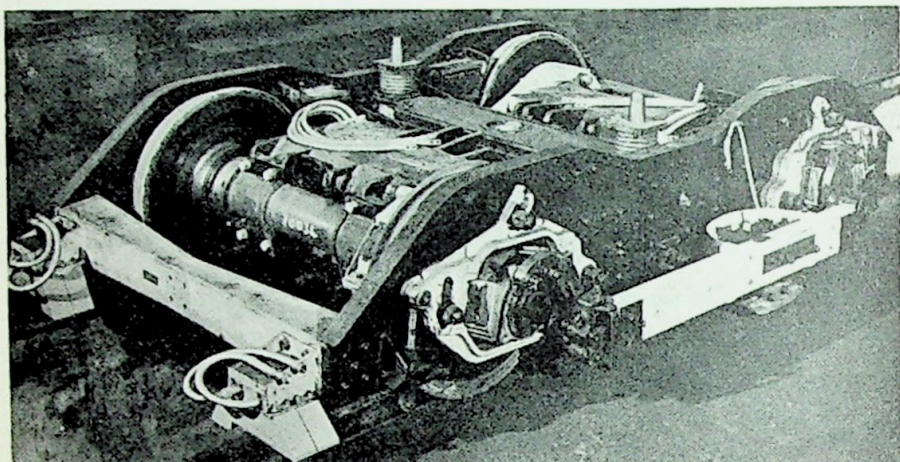


Figure 1 : Italian State Railways traction bogie for an E44 class 3,000 V d.c. electric locomotive, partly sectioned at right.
Dimensions in millimetres

In the previous paragraph mention was made of taking the braking and tractive effort forces to the locomotive body from a point low down in the bogie frame. This is done to avoid the phenomenon known as bogie pitch.



Bogie for Victoria Line motor-coach, London Transport. Note Metalastik primary springing for axleboxes, elastomer springs for secondary suspension and track circuit code pick-ups in front above rails

With a traction motor pinion mounted in front of or behind the axle-mounted gear wheel there is a tendency for the pinion to try and dive under the gear-wheel or mount above it instead of causing the gear and the locomotive wheels to revolve during acceleration. A low point for the transmission of tractive effort avoids this effect. In some locomotives where a low level for the transmission of tractive forces is not practicable the axleloading difference between the two axles of a bogie can reach as much as three tons and there is a danger that the lightly loaded axle will begin to spin. In d.c. locomotives a common method of avoiding the problem is to arrange that the motor of the lightly-loaded axle is one resistance bank step ahead of the other during acceleration. Thus the lightly-loaded pair of wheels is not called on to transmit so much power to the rails as the heavily-loaded pair. The bogie shown in Figure 1 does not have this provision, but to avoid body pitch between the bogies both motors in the front bogie are accelerated one resistance step ahead of those in the rear bogie.

Should wheel spin occur, and also wheel slide during braking, various automatic devices are now fitted to allow recovery. In the Yugoslav Railways class 342 locomotive an electronic device measures the rotation speed of each axle, a voltage thus being produced in a circuit proportional to the speed. Should the voltage given from one axle rise above the average value of that from the others, indicating a wheel spin, the apparatus sands the track in front of the offending axle and applies a brake to it in proportion to the

difference between the voltages recorded until the spin finally ceases. In another arrangement fitted to the Italian State Railways E444 class locomotive the electronic device inserts a resistance into the traction motor circuitry of the spinning axle, so reducing the power applied to the axle until the spin is over. Devices such as these are also adapted to relieving wheel slides in the case of over-braking of any axle. All the devices depend on wheel rotation speeds and thus will not work should all the axles of a locomotive spin or slide simultaneously. This is one of the reasons why the Advanced Passenger Train on British Rail will be fitted with a radar doppler effect speedometer, the speed indication of which is independent of the wheels and will be used to check wheel spin. Radar waves will be emitted ahead of the train which will be reflected back to it off the ballast and sleepers. As the train will have moved ahead before the incoming waves return the latter will be out of phase with the outgoing waves, the amount of phase difference being used to indicate the speed of the train.

In both diesel and electric locomotives power must be supplied for various auxiliary services. Principal among these are the various cooling fans and blowers (transformer oil cooling, for example, resistance bank cooling, traction motor cooling and on diesel locomotives the diesel engine cooling water radiator fan, although this latter is quite often driven direct from the engine crankshaft by a cardan shaft connection). There is also the compressor for the air brake and such compressed air requirements as air blast circuit breakers and additionally current has to be supplied for locomotive battery charging. The battery in turn supplies the locomotive lighting, excitation current for the traction motors and minor requirements, including powering the hotplate to warm up the driver's dinner. Modern practice is to have a motor-generator set which supplies three-phase a.c. to the necessary points to drive the electric motors of each piece of apparatus, a solid state rectifier also being supplied to allow battery charging. Many diesel locomotives take d.c. off the main traction generator for these services, but here too practice is changing to the installation of an auxiliary belt-driven three-phase generator. Sometimes a d.c. dynamo is directly coupled to the engine crankshaft, which has the advantage that it can also double as an engine starting motor when supplied with current from the battery. Current for heating the driver's cabs (and the rest of the train when fitted) is normally taken straight from the pantograph intake from the overhead contact wire; in the case of a.c. locomotives this current is transformed and rectified to 800 V or 1,000 V d.c., while the overhead wire or third rail voltages of 750 V, 1,500 V or 3,000 V are used direct.

Every schoolboy knows about the dead man's handle fitted to the driver's controller, the weight of the driver's hand resting on the controller allowing the locomotive to start and continue to run because electrical contacts are closed. Should the driver be taken ill his hand will slip off the dead man's handle on the controller, the contacts will open, power will be cut off and the brakes applied. Unfortunately, there have been cases where an unconscious driver has fallen across the dead man's handle and kept it depressed. Further,

as modern locomotives are almost entirely automated, there is correspondingly less for the driver to do and his attention may wander, particularly as his cab is now warm and comfortable. Vigilance devices therefore have been designed and widely used to supplement the dead man's handle (now using electronic circuitry) which work from the wheels and blow a horn in the cab after a pre-fixed distance has been travelled. To stop the horn a driver must press a button; failure to do so results in the train being stopped automatically. The driver's controller and the brake valve are included in the vigilance circuitry and the movement of either control during a distance cycle will re-start the cycle again from zero. It follows that the faster a train goes the more warnings a driver will receive, while when he is busy and using the locomotive controls there is little likelihood of him being distracted by warnings. As the warnings are irregular they are not habit forming and when the locomotive is at rest the warning system is automatically inoperative. This is a lot of ingenuity expended on keeping a man awake and alert, who knows perfectly well that if he is not awake and alert the likelihood is that he will be killed first as he rides at the front of the train, but such is human nature.

BRAKES AND COUPLERS

It has been said that any damn fool can start a train, but that it takes a skilled man to stop it. This I learnt for myself in an early attempt to stop a train at Walmer station in Kent. Despite manipulating the brake handle in what seemed to me to be the right manner the station buildings slid by and when the train finally came to rest only the last coach was still inside the platform. The driver and fireman were amused but the guard and the waiting passengers did not seem to regard the matter as funny. Fortunately no one wanted to get out of the coaches clear of the platform. I felt a bit better about this episode after a ride in a Marylebone to Sheffield train on a hard frosty morning about a dozen years later; the locomotive was in the charge of a driver who was presumably being paid to know what he was doing. We roared out of Marylebone, got up to a most unusual speed in the dip past Neasden and unfortunately carried on the effort a bit too far towards our first stop at Harrow-on-the-Hill. When the train was halted only the last two out of eight coaches were inside the platform. Afterwards we travelled towards Sheffield a little more sedately. On both of these occasions the vacuum brake was in use, which is now being displaced on the railways of the world by the air brake, and indeed the air brake has always been used by some countries since the braking of the whole train by the driver first began about one hundred years ago. The vacuum brake by its nature has not got a force greater than 14 lbf/in^2 (one atmosphere or so) at its disposal, whereas the air brake usually uses air compressed to 60 lbf/in^2 . For a given braking effort the latter apparatus is usually lighter and more compact if not so simple.

The air pressure is used to apply brake blocks, usually against the wheel treads, by means of a piston in a brake cylinder. A compressor on the loco-

motive supplies the air pressure, which is passed by a brake pipe with couplings between vehicle and vehicle all down the train to fill brake reservoirs and put the brake in working order. When the driver wishes to apply the brake he opens his brake valve to cause the pressure in the brake pipe to fall. A device known as a triple valve is thus actuated on each vehicle, which allows air from the brake reservoir on the vehicle to flow into the brake cylinder, in proportion to the drop in pressure in the brake pipe. Should the driver release all the pressure in the brake pipe the brake will go hard on and the same thing happens should the train break in half. The brake is released by restoring the pressure in the brake pipe, the locomotive carrying a large reservoir to provide air to assist this action. When the air pressure in the brake pipe rises the triple valves first release the air in the brake cylinders to atmosphere (the brake blocks then come off the wheels) and then recharge the brake reservoirs on each vehicle. The brake works excellently for short trains but for longer trains the wave of falling air pressure from the brake control the driver has opened to the far end of the train takes some time to travel, with the result that the front of the train is braked but the rear is not. This effect is chiefly met with in freight trains and various devices are used to mitigate it, as well as the slowness of building up pressure through a long pipe to release the brake. Quick acting and release brake cylinders have been designed and sometimes a double brake pipe down the train is used. Another difficulty in freight trains is that a given brake application has more effect on an empty wagon than on a loaded wagon. Many wagons are equipped with a manually operated empty or loaded lever, operation of which before the train starts results in a lesser brake application for empty wagons and a normal brake application for loaded wagons. The full answer to the problem of applying and releasing the brake simultaneously all down the train is given by the electro-pneumatic brake, in which the application and release signals are given electrically and the distribution of air follows up. The electro-pneumatic brake, in Great Britain at any rate, has been chiefly applied to metropolitan and suburban trains for which braking is frequent and speed is important, but its use has spread to main lines and electronic circuits now control braking applications.

It is a characteristic of electric motors that when run in reverse they become generators of electricity. Should the traction motors of a locomotive be reversed in this manner the force that runs the motor in its generator mode is the forward momentum of the locomotive and its train and as this force is dissipated by generating electricity there is a braking action. There are two forms of this electrical braking in use; rheostatic, in which the power generated is used to heat up an air-cooled bank of resistances (in d.c. locomotives the starting resistances are often pressed into service for the task) and regenerative, in which the generated electricity is passed back into the overhead line and becomes available to assist the driving of other locomotives. Rheostatic braking can be fitted to diesel-electric locomotives and electric locomotives can be either rheostatically or regeneratively braked. A certain amount of switching to provide an 'excitation' current (usually derived from

the locomotive's battery) is necessary before d.c. and low frequency traction motors can act as generators, in addition to bringing in the resistance bank in the case of rheostatic braking and switching on the cooling fans for the resistances. Ingenuity can produce economy; thus in the British Rail class 86 electric locomotive the traction current transformer is not required during rheostatic braking. Thus the transformer's cooling fan is speeded up for the task of cooling the braking resistances and baffles direct the cooling air on to the resistance bank. The driver merely switches to rheostatic braking and all the rest follows automatically, the driver's controller being used to increase the rheostatic braking force. Rheostatic braking in d.c. and low frequency traction motors cannot be used to anywhere near zero speed, they cannot halt the train. This is because the traction motors and possibly the resistance bank would overheat, so the air brake must be used for the final stop. Modern practice combines both the rheostatic and the air brake in one control handle. Thus on the Italian State Railways class E444 3,000 V d.c. locomotive the driver's braking handle operated at the top speed of 125 mile/h will bring only the rheostatic brake into use, but as the speed drops below 100 mile/h both brakes will automatically be brought into use. At 43½ mile/h rheostatic braking ceases and the train will be stopped by the air brake alone. In an emergency the driver is able to use both the rheostatic and the air brakes together at speeds above 100 mile/h.

The asynchronous traction motor is readily reversible without an excitation current and in the new German diesel-electric locomotive fitted with asynchronous motors described in the last chapter, the current inverter is reversible as well. In the braking mode the current inverter feeds d.c. back towards the solid-state rectifier (which the d.c. cannot pass) and this braking current is diverted to feed special braking resistances, which are cooled by a fan. In the braking mode on this locomotive the traction motors are in fact fed with a small current, because with its aid the locomotive and the train can be braked right down to a stop by the rheostatic brake alone; the only restriction is the capacity of the resistance bank fan to clear the generated heat.

Regenerative braking which turns the momentum of a train into electricity, that is then fed into the overhead line for the use of other trains, at first sight seems to offer considerable advantages. Nevertheless, there are snags. First of all, motor switching for excitation must be fitted on the locomotives in use on d.c. and a.c. systems (except three-phase in the case of the latter) and extra apparatus is required as well at lineside sub-stations where power is normally fed into the overhead contact wire. Secondly, should no other trains be drawing power at the time of braking, it may be that the voltage in the overhead line will rise to an unacceptable level. Overvoltage cut-outs can be provided on the locomotive, but should one of these operate it can leave the locomotive unexpectedly relying on the air brake alone, unless an emergency resistance braking bank is fitted in addition. Railways therefore are in two minds about regenerative braking. The 3,000 V d.c. Italian State Railways does not use it, the 15,000 V, 16⅔ c/s, Swiss Federal Railways just to the north does and the similarly electrified German Federal Railway to the north

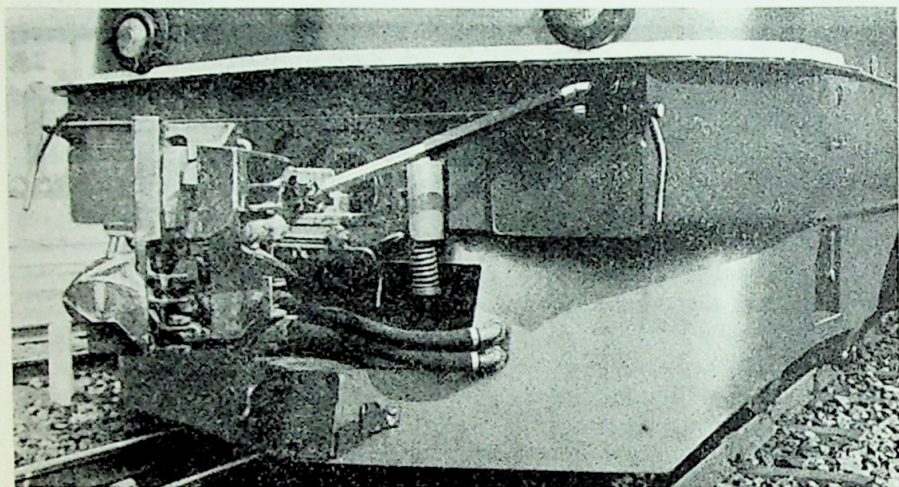
again does not. The new Tokyo metropolitan Chiyoda Line does use regenerative braking and indeed claims that it gives them a power saving of 20 per cent, but on this heavily-used railway the overvoltage cut-outs rarely operate.

For many years trains have been braked by cast iron brake blocks applied to the wheel treads. Cast iron wears and replacement of the brake blocks is necessary frequently, so a recent trend is the use of composition brake blocks based on a plastics resin which does not wear so fast. These composition brake blocks are especially popular on metropolitan railways running in tunnel, for cast iron brake blocks are worn down into dust and this dust tends to be blown by passing trains into electrical apparatus to cause short-circuits, both in the motor-coaches and in lineside apparatus. A disadvantage of composition brake blocks is that they can squeal at low speeds, amply demonstrated by French *grand confort* coaches on Trans Europe Expresses as they come to an ear-piercing halt. London Transport, another large user, manages to get by without this trouble. During the last 25 years disc brakes have been used on locomotives, motor-coaches and vehicles, which when the disc is mounted on an axle have the superficial appeal that four instead of the wheel's maximum of two brake blocks can be applied (sometimes the wheel brake block is split into a pair). In practice the generated heat from four brake blocks cannot be dissipated from the disc, despite careful design of the latter for maximum heat dispersal into the air stream of the moving train. It appears that the rail acts as a heat sink for heated wheel treads when braking is in progress and to take advantage of this the discs are now often fitted to both faces of the wheels, where only two brake blocks can be brought to bear. It has been found that with tread brakes operating at speeds above 100 mile/h the metal of the tyre is heated to such an extent that its nature alters with consequent danger of fracture. For this reason disc brakes are necessary on high speed trains, for although the same heating troubles might occur they do not have a direct effect on the running of the train.

One of the claimed advantages of the hydrostatic version of the diesel-hydraulic locomotive is that the locomotive can be slowed down by slowing the engine speed in comparison with the wheel speed, although in practice the advantage does not often appear. Hydrodynamic brakes can be added to the Voith hydrokinetic transmission, first done in Germany in 1964 after the hydrodynamic brake had been tried out in the United States a year or two before. The British Rail Advanced Passenger Train is to be fitted with a hydrodynamic brake and in this case the brake will be separate from the transmission. A drum filled with a braking fluid will surround certain axles, the braking fluid being constantly circulated into and out of the drum for air cooling. The revolving axle will drive blades through the fluid in the manner of a fluid coupling and when braking power is required the inlet and outlet apertures to the drum will be restricted, the fluid then resisting the passage of the blades more strongly. This will slow the train down and the lost momentum will be converted into heat in the braking fluid. Finally, mention should be made of magnetic brakes. An electro-magnet energised on the

train will try to grip the rails and thus have a braking effect. Electro-magnets are often fitted to motor-coaches and sometimes to ordinary passenger coaches as an emergency brake, but as it is suspected that such braking may damage the track this brake is normally regarded as a last resort.

The familiar European buffers and link couplings are on their way out after a life of well over a century. All vehicles suitable for international



European automatic coupler fitted to a Swiss Federal Railways Ae6/6 class locomotive

service are to be changed over to automatic couplers at Easter 1981 and most European countries will change over all rolling stock completely in the next year or two. Only Great Britain, Turkey, Greece and Iberia will retain some rolling stock not in international use with buffers and link couplings, to avoid expense and for various other good reasons. A design of automatic coupler has been agreed and stockpiling is about to begin. The cost for western European countries plus Yugoslavia is estimated to be £600 million at 1969 prices and a five per cent return will be earned on the money. This is not very much but there are additional advantages not easy to quantify, including the saving of some 50 railwaymen's lives each year. The automatic coupler is mounted in the centres of the ends of the vehicles and couples on the vehicles being brought together. Uncoupling is a matter of pulling a lever at the side of the wagon or coach; there is no need to go on the track between the vehicles. The automatic coupler is an old idea and a version called the Scharfenberg coupler has been widely used in Europe since the 1930s, on special rolling stock that does not ordinarily couple with other vehicles. This includes high-speed multiple-unit train sets, suburban multiple-unit sets and metropolitan line stock. The Netherlands Railways operates most of its passenger services with electric multiple-unit and diesel railcar train

sets and the whole lot are fitted with this Swiss Scharfenberg automatic coupler. The coupler does not only couple, it also connects the train air brake pipe automatically and makes good up to one hundred train control electrical circuits (including high-tension train heating circuits) by bringing copper studs into contact with one another. Two prototype multiple-unit train sets for the Southern Region of British Rail brought the Scharfenberg automatic coupler to Great Britain in 1971.

The United States was fully-converted to automatic couplers by 1900 and many other railways in the world also use them; quite a lot of British Rail main line coaches are fitted with this United States automatic coupler. The coupler has certain imperfections and about 1915 the improved Willison coupler was designed. Unfortunately the Willison type could not couple with the existing type in use in the United States and the railroads there were unwilling to make a change. So the American designer took his coupler abroad with some success in the 1920s. An Algerian narrow-gauge line, the Blida-Djelfa, was equipped and far more importantly the infant Soviet Union Railways took the coupler up. By the late 1950s all the vast Soviet Union railway system was completely converted to the Willison type of coupler—the word type must now be tacked on to the word Willison for there were improvements along the way but the principle remains the same. Also, by the 1950s European railways were thinking of what type of automatic coupler to adopt, for it was becoming obvious that there were savings in operating expenses to be gained. Many Soviet wagons could be converted from the 5 ft gauge to the 4 ft 8½ in gauge at frontier points to run in the rest of Europe and other railway administrations also owned these convertible gauge wagons. Partly because of the existence of these wagons and partly because some eastern European countries looked to Russia for the manufacture of the automatic couplers, the Willison type coupler has been adopted for all Europe. Like the Scharfenberg coupler, with which the type is not compatible, the Willison type will now also couple the train air brake pipes and the necessary electrical control circuits as required.

Some major European railways have run trial trains equipped with the automatic coupler to gain experience, but not without some troubles as the majority of European freight wagons are four-wheelers. As has been noted the application of the air brake by the driver of the locomotive will take time to pass along the train and the brake on the last wagon is applied a perceptible interval after the brake has gone on in the first. With centre automatic couplers it was noted that the unbraked four-wheel wagons at the rear of a train, when bunching up against the braked wagons at the front, took up a zig-zag formation. That is, one wagon would twist on the rails to the left, the next would twist to the right and so on. With side buffers this twisting effect on bunching was to a large extent prevented. Finally, when the German Federal Railway had a long trial automatically-coupled freight train running at over 60 mile/h, a driver made a hard brake application (but no harder than one made normally in ordinary service) and a considerable number of four-wheel wagons at the rear of the train zig-zagged themselves off the track

altogether. That made European railways think a bit, for it looked as if most freight trains could not exceed, say 45 mile/h, until all the four-wheel stock had worn out. The first reaction was to step up the building rate for bogie wagons with which zig-zagging does not occur; fortunately too the average size of freight consignments is going up so bogie wagons will be needed. Then thoughts turned to equipping at least a proportion of the four-wheelers with the electro-pneumatic brake so that the brake was applied simultaneously right down the train, but this hit a snag. For good and satisfactory reasons the Soviet Union Railways and east European railways wanted this electro-pneumatic brake to work at one voltage, for equally good and satisfactory reasons the west European countries wanted another voltage. European railways have been happily co-operating internationally for over eighty years; this was one of the few occasions when they agreed to disagree. Currently, agreement is being sought for a cheap switch and simple circuitry to allow wagons to be switched from one voltage to another at frontier points.

ROLLING STOCK

The suspension of rolling stock on its wheelsets follows much the same lines as described for locomotives, although as the weights involved tend to be lighter the assemblies are lighter too. For passenger vehicles, where soft springing and freedom from lurches and vibration are called for, combined with the ever-present need for low maintenance costs, the design problems become very complex and computers have been called in to deal with the necessary calculations. It is still common to use a bogie pivot, which is mounted in a transverse beam called a bolster, the latter having slides at each end to support the body sides. The bolster is hung by swing links and secondary springing from the bogie frame. Articulated traction links are often provided between the bolster and the bogie frame, both to pull the latter along and to transmit braking forces from the wheels. Secondary suspension in modern practice is coming to be supplied by air springs, a bag of air in an elastomer container. These are particularly used for metropolitan rolling stock, for an automatic device to vary the quantity of air in the spring according to the number of passengers the coach is carrying can be included, thus adapting the springing to the load. It is also being recognised that if freight trains are to run at higher speeds the wagons must be fitted with secondary springing in addition to the primary springing now fitted. Both passenger and freight stock bodies are built of steel, which requires anti-corrosive protection and painting. To save weight, aluminium sheets, stainless steel and light alloy castings are being much used, which have the additional advantage that often no painting is required. Passenger coach bodies have to be insulated, both against changes in temperature and against noise; a variety of rubbers, plastics foams, heat insulants, mastics and so on are used between the outer and inner panelling, beneath the floor and under the roof to ensure this insulation.

Heating, lighting and ventilation of passenger coaches are subjects of great interest to travellers by train, so much so that these matters almost seem more of a publicity and public relations difficulty than technical problems to be solved by the railway engineer. For many years steam from the locomotive was used to warm coaches through radiators under the passenger seats. Steam heat is still general throughout Europe, the steam now being supplied from boilers on diesel and electric locomotives or occasionally from boilers mounted in special 'heater vans'. Electric trains, particularly suburban multiple-unit trains which do not normally run with other rolling stock, have been electrically heated for at least 50 years and since the second world war electric heating has become general in Europe; for the time being coaches are fitted for both steam and electric heating. Coaches on international services must cope with the various electrification systems in use and their heating circuitry is arranged to work on 800 V, 1,000 V, 1,500 V and 3,000 V d.c., the first two voltages being rectified from a.c. electrification systems. Jumper cables and connections for the heating circuits are provided on the left-hand ends of each vehicle. With the rise of electric heating and even before, apparatus was devised to warm air which is then blown into the compartments and saloons of the coaches. Heating by warm air distribution can assist ventilation and can also help with cooling during the seasons of the year when the heating apparatus is out of use. Electric train lighting has been in use for many years, usually provided by a d.c. generator in each coach belt-driven from an axle which charges a battery from which the lighting current is taken. Modern practice substitutes a maintenance-free a.c. generator driven from an axle by a cardan shaft, the output being solid-state rectified for d.c. to charge the battery. Lamps are often substituted by fluorescent lights, the a.c. necessary for the lights to operate usually being provided by a small current inverter on each one.

Full air-conditioning of railway coaches started in the United States in 1928 and rapidly spread in that country, while on many other railways throughout the world air-conditioned individual coaches appeared during the 1930s, e.g., sleeping cars in Great Britain. Power for air-conditioning was supplied from axle-driven generators and these absorb on average about 40 hp for each coach. For complete air-conditioned trains running on mountain railways, and later on for high speed trains in Europe, this 40 hp per coach was a considerable drain on the locomotive power available for the primary purpose of traction. Therefore, these trains came to be equipped with independent diesel-generator sets to supply power for air-conditioning and other purposes, carried in a van or elsewhere, e.g., British Rail Pullman diesel railcar sets and the French *grand confort* coaches for Trans European Expresses. From such luxury trains air-conditioning spread to the ordinary passenger and several European railway systems placed standard air-conditioned coaches into service from 1971. Air-conditioned coaches for ordinary service necessarily take their power supplies from the locomotive to avoid a multiplicity of power vans, usually direct through the circuits that provide for coach heating. In some coaches there is a mixed system with heating supplied direct from the

locomotive and other power requirements taken from an axle-driven generator, which in any case is required for lighting. Air-conditioning is a wide subject and there is no space here to go into all the problems that come up in railway applications, except perhaps to record one railway oddity. Widely separated railway systems over the world have elected to give the passenger who is riding in a compartment some control over the compartment's temperature and occasionally over the humidity level as well. Nevertheless, all railway administrations are agreed that the passenger riding in a saloon coach has to take what he gets and no controls are provided for him. Air-conditioning has now won through as the solution to all the heating and ventilation problems that have plagued the railway engineer almost since the birth of railways.

To summarise a chapter such as this in which a diverse range of subjects has been covered is difficult. The reader will have noticed the general railway tendency towards automation wherever possible, aided in recent years by electronic circuitry, coupled with design aimed at minimum maintenance. Design too is also directed at ease and economy in manufacture. Maintenance tasks that are unavoidable and coping with failures are being simplified by modular construction, particularly for passenger coaches. That is the apparatus that it is wished to inspect or repair can be disconnected and removed bodily, its place being taken by a similar module of freshly inspected and repaired apparatus. To allow this to take place it follows that there is ready access to all apparatus and this simplification of maintenance procedures allows expensive railway equipment to be kept in service for long periods. Costly manpower needs are also cut to a minimum.

CHAPTER FOUR

Signalling

It early became apparent that railways required some control system if trains were not to meet on the same line, for even if there were not collisions, severe delays were likely while precedence was decided. Fortunately, the electric telegraph was developed shortly after the first main-line railways were built in the 1830s and with its aid to communicate between railway station and railway station successful operation was ensured. The telephone joined the telegraph in the 1880s and even today it is probable that the greater part of the world's railway route mileage is worked by the use of one or the other. The ability to exchange messages between stations led to the railway route being divided into sections between the stations and the rule has become everywhere accepted that no more than one train is to occupy one section at one time, especially if trains are being operated in both directions over a single track. There are exceptions to every rule and occasionally trains moving in the same direction are allowed into a section together. In Great Britain this applies to freight-only tracks where slow moving trains follow each other at sight, while on the Tunisian National Railways, for example, where there are very long single-track sections, one train is allowed to enter the section following another after a time interval, in this case 20 minutes. Wireless communication is usually unsatisfactory for train working, for it is at first necessary to establish that the wireless waves will never be interrupted or fade at any time. On a few railways conditions are such that wireless can be used; the Bong and Lamco iron ore railways in Liberia, the similar railway owned by Miferma in Mauritania and a Dutch rural branch line over the flat Friesland province are examples.

At first, the man in charge of the telegraph gave a hand signal to the driver that the section ahead was clear (it is still done on some railways) but railway signals had come into use even before the telegraph. Minimum equipment was a signal to enter the station yard, one for each direction of approach and usually known as home signals, but soon a starting signal to enter the section ahead of a train was added and then a marker or warning signal before the station. This latter signal alerted the driver as to his whereabouts, particularly at night, and if the warning signal was at caution he prepared to stop, if necessary at the home signal guarding the station. Signals at night have always

displayed a red light for danger, but in Great Britain and elsewhere a white light was used for line clear at first. In Great Britain white was almost immediately abandoned for green to show line clear, but this did not occur on the Tunisian National Railways until 1969 and perhaps it was the last major railway system in the world to use white for the line clear indication. Yellow as the caution aspect of a warning signal was first used in the 1880s, in Italy it is claimed. These three colours are used generally throughout the world for danger, caution and clear, but other colours are used as well, together with combinations of colours and flashing aspects, each country tends to have its own system of signal indications. The signals were manipulated from levers at the station by means of wires. As the number of signals increased separate signalboxes were provided for the lever frames and points were operated from the signalbox as well as by means of rodding. From the 1880s hydraulic power was used to operate signals and points and is still used here and there.

It soon occurred to the pioneers that it was all very fine being able to operate signals at a distance, but supposing a careless signalman put two signals to clear to bring two trains simultaneously on to one line and cause a collision? The first interlocking signal frame was erected at Bricklayers Arms Junction outside London Bridge station where two double line routes met in 1846. It was a simple affair controlling four signals and ensured that no signal could be put to clear if another one was already at clear for a conflicting movement. When the movement of points was brought into the signalbox these too were incorporated into the interlocking system and by the 1860s the mechanically interlocked signalbox was of great complexity, so much so that the signalman was quite inhibited from making a false move. Various working rules were evolved to supplement the interlocking, which are still in force. In Great Britain it was laid down that the line must be clear for 440 yd behind a stop signal at danger that was likely to be approached by trains at speed with only a warning signal in front of it. This 440 yd overlap is provided in case the driver of the train fails to stop it in time. Unless the signal protecting points could be sited at least 440 yd from them this led to delay because the approaching train had to be held at the previous signalbox which could be some miles away. So another rule was evolved, the train could be allowed to proceed beyond the previous signalbox provided the signalman there stopped it and informed the driver that the section ahead was clear but the station or junction was blocked. Train working rules and indeed the amount of interlocking in the signalbox vary from country to country and the above rules are only examples taken from one country with no universal application. The rules like the interlocking all have one simple safety aim, the prevention of trains trying to occupy the same stretch of track at the same time.

One of the difficulties of the signalman was to know where the trains actually were. On occasion signalmen have missed the passing of a train outside altogether when distracted by other matters, or even worse have imagined a train has passed them when it has not. The latter sounds unlikely,

but in a signalbox on a dark and blustery night it is quite easy to be convinced that a train is passing outside and even to get the impression of a train's red tail lamp briefly glimpsed as it vanishes down the line; some memorable railway smashes have occurred for these reasons. Electricity came to the aid of the signalman in the 1880s in the form of the track circuit. A length of track was insulated from the rest and the leads from a battery connected, one lead to each rail. At the other end of the insulated length an electrical relay was connected, which was normally held closed by the current flowing through the rails. A train running along the stretch of track causes a short-circuit through its steel wheels and axles and the relay contacts open as it is no longer receiving current from the battery. In a simple case a warning light in the signalbox goes out to indicate the presence of a train, more importantly the breaking of the circuit in this manner can be arranged to show a danger aspect at the signal guarding the track-circuited stretch of track concerned. Should any fault develop in the track circuit that causes the relay to lose current, the contacts will open and the signal go to danger, a safety feature. The sleepers and ballast of track are sufficient for the insulation of low track circuit currents, but the rails must be divided up into track circuit sections (usually called track circuits *tout court*) with insulated joints at each end. To jump ahead a little, the rails on electrified railways are used to return the traction current to earth and insulated rail joints are incompatible with this use. For this reason each insulated joint on track-circuited and electrified railways is bridged by an impedance bond. The electrical resistance of this bond is high enough to stop the low track circuit current but low enough to pass the heavy traction return current. On d.c. railways the traction return current would swamp a d.c. track circuit current and for this reason a.c. track circuits first came into use, the a.c. being supplied from an outside power source.

Track circuits are put to use in two ways, to inform the signalman and to operate the signals. For the information of the signalman the original lights in the signalbox were soon evolved into an illuminated track diagram, which is a feature of all modern signalling installations. The whole of the track controlled by the signalbox is divided up into track circuits and the diagram is a plan of all the track similarly divided up into track circuits. There are two types of illuminated track diagram; in one, the older, the tracks in the plan are lit up and these lights go out where any track circuit is occupied by a train. In the other type the diagram is normally dark, thus saving electric current and preventing the generation of heat, and the train lights up its position as it runs along, track circuit by track circuit. The signalman can be shown the position of all the trains in his area and in many modern installations the signalman does not see the trains at all, unless he is inclined to take a stroll to a window to see how the weather is getting on. In modern signalling installations described below the illuminated track diagrams can give even more information. For example, should a train be passing non-stop through a large station the signalman sets the points and clears the signals beforehand. This cleared route may cover a dozen track circuits or more and when the route is set up it appears on the diagram as a line of white light.

The train when it enters the first track circuit shows its position by a red light and this red light progresses across the diagram swallowing up the white light track circuit by track circuit. In really modern signalling installations the previous signalling installation sets up the train's number at the edge of the diagram and this number follows the red light across the diagram and very often it is arranged that this number is handed on automatically to the illuminated track diagram in the next signalling installation.

Secondly, and more importantly, the track circuit is used to operate signals. In principle, after passing a green signal the train enters a track circuit which puts the signal to red, which it maintains until the track circuit is unoccupied again no matter what the signalman does. It was quickly realised that in the case of a station with no points it could be automatically signalled without the services of a signalman. Consider a station with a warning signal, a home signal and a starting signal. Four track circuits are provided, two between the three signals and two beyond the starting signal. Initially, all signals are at clear as a train approaches. As the train passes the warning signal it enters a track circuit which sets the warning signal to caution behind it. On entering the station past the home signal the train closes the second track circuit and the home signal goes to danger, the warning signal already being at caution. When the train leaves the station it enters a short track circuit after the starting signal, which represents the 440 yd safety overlap. After leaving this short track circuit the home signal controlling entry to the station will go to clear. The starting signal will remain at danger as long as the train is in section. As the sections between stations can be long it is often arranged not to have a track circuit throughout the section but to have a treadle controlling an electric switch after the home signal of the next station. When the train's wheels depress this treadle, all three automatic signals of the previous station will finally show clear once more.

In practice, where automatic signalling is installed the sections are much shorter than in the example given above and often only amount to the distance between stop signals. In such a case the warning signal for the next stop signal is placed beneath the previous stop signal. Full automatic signalling is applied to open sections of the line with no points, but frequently stations where the points are required to be used at certain times of day only are arranged so that the signalling can be switched to automatic operation for through runs through the station when required. In all signalling the stop signals go to danger behind the train when the train is occupying the appropriate track circuit, and remain at danger whatever the signalman tries to do. The track circuit is now basic to the safe working of the railway wherever traffic is high enough, although there are many railways all over the world where traffic is so low that the cost of track circuits does not allow their installation and older traffic working methods prevail. In the past in Great Britain there has been an outcry from the public for light cheap railcars to cut costs and thus allow some insolvent branch lines to operate. Railwaymen had various objections to light railcars, one of them being that the railcars were apt to be so light that they failed to operate track circuits because of inadequate electrical contact with

the rails. Maybe the branch lines on which the railcars worked were not track circuited, but the junction stations from which they worked were equipped and in any case in their occasional comings and goings on the main line the railcars were unsafe, which made for all sorts of operational difficulties.

Track circuits were first used in the United States but during the 1890s they had application in many other countries and during the decade the first automatically-signalled railways appeared. The Budapest underground line in Hungary, opened in 1896, for example, was track-circuited and automatically signalled, using colour light signals too although these were just an ordinary electric light bulb behind a sheet of coloured glass. There was also a move towards electric signalboxes (Great Britain had its first, in London at Granary Junction, Spitalfields, in 1898) but for a long time the use of electricity merely relieved the signaller of the manual labour of pulling over mechanical levers to operate signals and points sited some distance away. Interlockings remained mechanical and electricity was used to send the message to the signal or points to be operated, where pneumatic or hydraulic power did the actual work. When London's deep level 'tube' railways were opened in quantity from 1906 they were equipped with electro-pneumatic signalling, both for the signals (both automatic and controlled) and for the points. Before the all-electric signalbox became a practical proposition, engineers had to be satisfied that the electric relays used would operate every time over considerable periods and just as importantly would operate first time after days or perhaps weeks of inactivity. The all-electric signalbox became common in America and in the rest of Europe, if not in Great Britain, after the first world war. Miniature signal levers were pulled by signalmen just as in electro-pneumatic or hydraulic signalboxes but the signals and points were worked by electric motors and the interlocking was electrical by means of relays. When a lever was pulled to set a signal at clear, contacts closed to send the message and the same action caused relays to prevent any sending of a message to other signals for a conflicting movement—very often too it was arranged that the movement of signalbox levers for conflicting movements was physically prevented. Furthermore, a train standing on a track circuit sent an electrical message to the interlocking that prevented any other train being signalled on to that piece of track.

Between the wars electric light signals came into general use in place of mechanical signals. There are two varieties of these, colour light in which each signal aspect required has a separate electric lamp which is either lit or extinguished, or searchlight in which a spectacle plate with two or more colours is moved electrically across a single lamp. There are arguments for and against both types and the choice often seems to be quite arbitrary, thus in Great Britain the colour light signal has been made standard, whereas in Italy it is the searchlight type. Italy also goes in for flashing signal aspects which have yet to be introduced into Great Britain. The reason for the flashing aspects is that Italian signals since 1947 have told the driver what speed to run at, the speed command varying with the route that the train is to take and more signal aspects are thus required. Great Britain still maintains

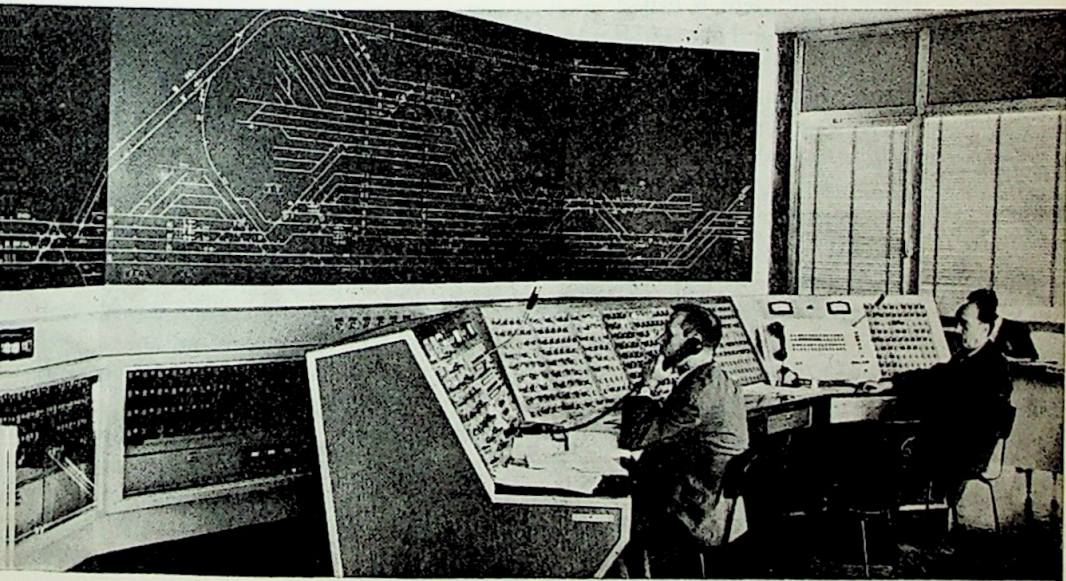
the older practice of showing the driver which route the train is to take and relying on the driver's knowledge of the road so that he adjusts the speed of the train accordingly. With higher speeds now being called for this British practice may change and the significance of signalling for a speed rather than a route will also be appreciated when automatic railways are considered in Chapter Five. A point that held up the introduction of light signals was, what happens should the lamp bulb burn out and leave the driver with no signal? This is normally met by arranging the circuitry so that in the event of a lamp bulb burning out and thus breaking an electric circuit the signal before the failed signal goes to danger. In addition a failed lamp leads to automatic switching to a spare lamp circuit.

When all-electric signalboxes reached Great Britain it was in a form that was an advance on previous signalboxes. Up to that time electric signalboxes were arranged just as the old mechanical boxes had been, that is the signalman had to pull a lever to operate each individual signal and pair of points. At Thirsk in north-east England in 1936 the first route-relay interlocking was installed, in which a signalman by turning a single switch could set all the points and clear all the signals for a complete route through the station without further action. Several other route-relay installations were put in before the second world war in the area concerned and but for the war all York Station would have been controlled from such an installation by 1942, but this installation had to wait until after the fighting was finished. After the war route-relay installations came to be used all over the world, at first with switches but latterly with simple push buttons to set up the routes. With the switches the signalman had to wait until the train had run through the set up route before he could switch back the route to clear. The push buttons merely set up the route and the train itself clears it, track circuit by track circuit, the signalman has no further action to take. Another advantage is that as the train clears each track circuit the route behind it becomes immediately available for some conflicting movement, there is no need to wait until the train has run through the whole of the route that has been set up. It should perhaps be added that there are two varieties of push-button signalling installations. In one the signalman is presented with a panel of buttons, each button carrying the number of the route it sets up. In the other, the entrance-exit type, the illuminated track diagram is brought down within the signalman's reach and the buttons are mounted on the diagram. The signalman is required to press a button at the entrance of the required route and another button at its exit.

One of the advantages of power signalboxes, both assisted electrical and all-electric, is the possibility of operating points and signals at distances too great for mechanical means. At first this capability was used to replace several mechanical signalboxes with one power installation at large stations. With the coming into use of route relay installations it became possible to control long stretches of line including several stations, always provided that a way could be found to avoid the vast quantity of cables necessary between the central interlocking and the various signals, points and track circuits. Fortunately, the

post-second world war development of electronics provided the solution. It is now the practice to have slave interlockings close to the place that is controlled and to pass commands in the form of electronic telegrams from the central interlocking to the slave over as few as four wires. Two of the wires are used to synchronise the electronic events in the two interlockings. The third outward wire from the main interlocking carries an alternating current, each wave of which can be amplified if required. There are say 250 electronic transmitter units or gates to vary the amplitude of a wave when required and correspondingly 250 receiving gates at the other end. Both transmitters and receivers are binary units, that is they can only transmit and receive two kinds of messages, represented by a normal wave or an amplified wave. The transmitter gates are run through in order and simultaneously the corresponding receiver gates open to receive the message, the whole process being repeated time after time and each telegram cycle taking a second or so. Should a signaller press a button to set up a route this is translated as a wave of increased amplitude transmitted by say the 198th gate. The 198th receiving gate recognises the increased amplitude of the wave and causes the slave interlocking to set up the needed route. Meanwhile, the fourth wire is transmitting signals by similar means from the slave to the main interlocking and will duly report the setting up of the route by the 198th gate, for confirmation as well as to alter the illuminated track diagram, in addition reporting the occupancy of track circuits and so on. In some installations the control centre has no interlocking at all and all relays are at the slave units, one such is the solid-state installation controlling the Milan Metropolitan, which among

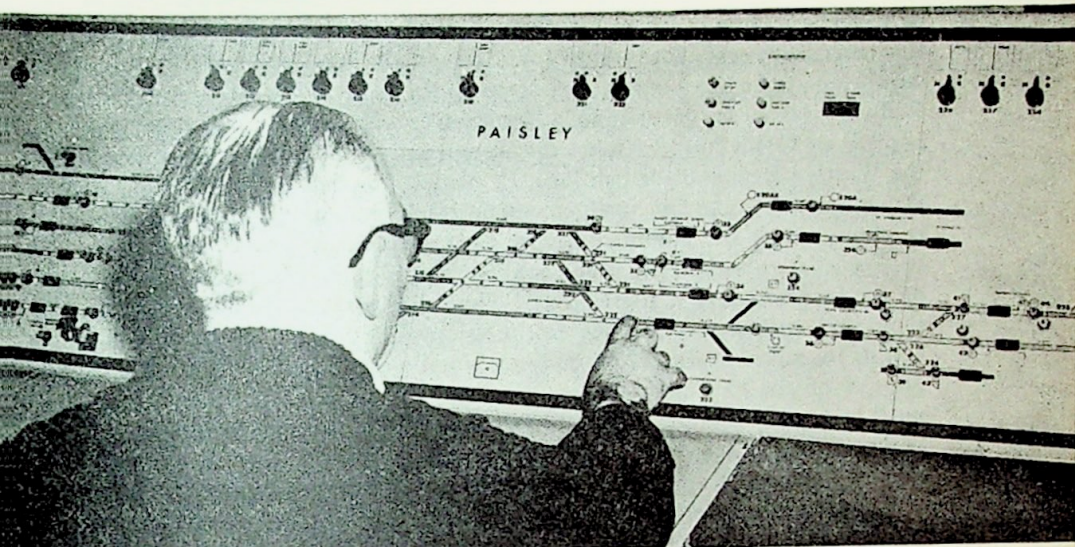
Route relay push-button signalling installation at Sampierdarena, outside Genoa, Italian State Railways



other duties prints out a graphical timetable to show just how all the trains on the line ran during a day of operation.

With route-relay signalling installations and electronic communications there is practically no limit to the area that may be controlled from one point, the ambitions of the signal engineer are only tempered by reflecting on the enormous number of trains that would be brought to a halt should a control centre be burnt out by a fire or put out of action for some other reason. About 100-150 route miles of railway appears to be a normal installation scope. The apparatus is of course expensive to instal, but train operation is greatly facilitated and above all there is a great saving in wages. The 99-mile journey from London's St Pancras station to Leicester is at present controlled by over fifty old signalboxes, almost all of the mechanical type operating old semaphore signals. In contrast, the 113-mile journey from Euston to Birmingham is controlled by only eight modern signalling installations and the 118-mile journey from Paddington to Bristol by only five. In 1969, when British Rail opened three modern signalling installations at Derby, Trent Junction (between Derby and Nottingham) and at Saltley in Birmingham, 550 signalmen were displaced from their jobs. When the St Pancras-Leicester route gets new signalling it is planned to have only two signalling installations, one at each end. Labour saving on this scale can pay for large amounts of modern equipment. It should perhaps be emphasised that older signalling methods are just as safe as modern installations, nor do they have any effect on train speeds for the moment. The nominal maximum speed northwards out of St Pancras is 90 mile/h, out of Euston 100 mile/h and out of Paddington 95 mile/h and these limits are set by the motive power and the track rather than by the signalling. Modern signalling has another side effect on the economics of the railway. In order to reduce signalling capital expenditure the traffic department is called upon to justify every siding and every loop line existing over and above the running lines. It is often apparent that many past facilities really are not now required and that they can be profitably eliminated.

Elsewhere in Europe the railways in general are not going so far as British Rail in signalling rationalisation. The approach is first to equip all the stations with their own route-relay interlockings and then to set up centralised train controls from which all these local interlockings can be worked. The local interlockings are thus still available for shunting movements if required and of course can take over in the event of any failure of the centralised train control. The 82-mile Circumvesuviana Railway, which runs a number of narrow-gauge local lines in the Naples area, has recently re-signalled with 46 route-relay installations, but the whole railway will be worked eventually from a centralised train control now building at Naples. Similarly, the 295-mile main line now being built in Yugoslavia from Belgrade to the port of Bar will possess 31 route-relay interlockings when it opens in 1973. It is planned that these will be worked eventually from centralised train controls at Belgrade and at the intermediate stations of Požega and Titograd. The Italian State Railways is building a new 155 mile/h railway over the 160 miles between



Operating the entrance-exit type route relay push-button signalling installation at Paisley, British Rail

Rome and Florence and when this is completed both it and the old route now existing will be signalled from a single centralised train control, but the old signalboxes will be retained and a number of new ones will be constructed on the new route. These continental methods give maximum protection against failures but they are certainly more expensive than British practice.

CAB SIGNALLING

Sophisticated signalling is all very well provided that the drivers of trains see and obey the signals. The possibility that they will not for one reason or another has always been in the minds of signal engineers and many pieces of apparatus have been devised to bring the train to a halt should there be errors. One method evolved in the United States was used on London's underground railways from 1906, where it is still standard equipment and known as a train stop. When each signal is at danger an arm rises from the ground beside it, close alongside the rails. Should a train pass the danger signal the raised arm hits a lever on the train, which on being pushed aside opens a valve in the train air brake pipe. The release of the train pipe air pressure brings the train to an abrupt halt. Crude but effective, especially for the comparatively low speeds of metropolitan trains. Should a signal fail it goes to danger and in certain circumstances the driver is authorised to pass the failed signal provided that he goes dead slow beyond. He is of course 'tripped' and stopped at the signal and has to get out of his cab and re-set the train pipe air valve brake lever before going forward. It is noteworthy that the only two accidents to

passenger-carrying trains in London's deep level 'tubes' have occurred while this emergency procedure was in force. About the same time as this train stop was being applied to London's underground railways, the old Great Western Railway was busy developing a locomotive cab signal. This was widely applied on GWR lines between the wars and is still standard equipment on the Western Region of British Rail. In British practice a clear warning signal shows that the home and starting signals are at clear and that the train is free to run through the station into the next section. A short ramp is placed between the running rails near each warning signal, which raises a plunger on the locomotive as it passes over. When the warning signal is at clear the ramp is electrified and the effect in the locomotive cab is the brief ringing of a bell. If the signal is at caution the ramp is not electrified and the raising of the plunger on the locomotive causes a horn to blow. The blowing of the horn must be rapidly acknowledged by the driver, if he does not acknowledge, the brakes go on automatically. The usefulness of this apparatus for main line train operation will be appreciated, especially during fog or misty weather.

British Rail standard cab signalling involves electro-magnets on the ground between the rails and on the locomotive. The locomotive magnet is opposed to the first track magnet and as the locomotive passes over, induction knocks its own magnet to one side, with a switching action. The second track magnet a few yards off is energised if the signal is at clear and restores the locomotive magnet to its previous position. If the signal is at danger the second magnet is not energised, the locomotive circuitry then causing a horn to blow and a visual signal to be displayed. Should the driver not acknowledge these signals, the brakes are automatically applied. Cab signals of this description, or on the lines of that of the GWR, are used on a number of railways in the world, notably the German Federal Railway inductive Indusi system. Fifty or 60 years ago another form of cab signalling was devised in the United States, using the track circuit to initiate the signals in the cab. The previous cab signalling systems described are intermittent, that is they report the position of a specific signal as it is passed. Systems based on track circuit current on the other hand can be continuous, for whenever the track circuit current alters this can be reported by the cab signal, whether or not a lineside signal has been passed. Should a warning signal at caution go to clear the moment a locomotive of a train has passed, this will appear at once on the cab signal, whereas with intermittent cab signalling the driver of the train would continue braking until the clear home signal came into sight, thus losing a minute or two.

Before going on with continuous cab signalling a word must be said about how a.c. track circuits are worked. The a.c. track circuit has other advantages beside its necessary use on d.c. electrified railways and hence it has come to be applied in many different places. There is a snag in using a.c., it was found that in certain locations that rails that should have had no current flow (because the track circuit had been short-circuited by the presence of a train) in fact had a current induced in them from the rails of a different track circuit alongside. This difficulty was overcome by coding each track circuit by

means of make-and-break contacts known as vibrating reeds or pendulum switches. The job nowadays is often done by solid-state switches. Thus for example the track circuit ahead of a signal in the clear position can be coded at 270 pulses/min, ahead of a warning signal at caution 180 pulses/min, ahead of a signal calling for a speed limitation 120 pulses/min and ahead of a stop signal at danger 75 pulses/min, these being actual pulse rates in use on the Italian State Railways. Behind the stop signal at danger there is no current, for the track circuit is guarding a train or a conflicting route. When the appropriate track circuits behind the stop signal are cleared the signal will show a caution warning or a restricted speed indication and the track circuit coding ahead of it will change to 180 or 120 pulses/min, eventually when the signal is at clear the track circuit pulse will change to 270 pulses/min. The apparatus circuitry is arranged to take the pulse rates in order and thus should a 270 pulses/min rate be induced in a track circuit that is supposed to have no current the spurious signal will be disregarded. It will be noticed that the codes are fail safe, no code present in the rails for whatever reason indicates that a train must stop immediately. In passing, it may be mentioned that induced currents are a tiresome problem in signalling, especially from industrial frequency electrifications and now thyristor control of traction current. A normal method of protecting signalling cables is to screen them by an insulated metal sheath incorporated into the cable. A low current is passed through the metal sheath and any induced currents or frequencies affect this low current which does not matter. The signalling wires inside the cable are unaffected and safe.

Given the presence of pulsed track circuits, a couple of collecting coils mounted just above the rails in front of a locomotive can have similar pulses induced in their circuitry. The coil current when decoded and amplified can be used to work a cab signal which reproduces the message of the track circuit codes. Thus, when a 270 pulses/min code is being picked up the cab signal will display a green light for clear, while should the train move on to a track circuit coded at 180 pulses/min a warning indication will appear and so on. Should an indication calling for a lower speed appear on the cab signal, the driver has three seconds to acknowledge it before the emergency brakes go on, the required acknowledgement usually being the movement of the brake handle to apply the brakes. Where speed signalling is in force both the 180 pulses/min and the 120 pulses/min codes can be used to call for a reduced speed as well as heralding the approach to an eventual stop signal. The circuitry on the locomotive can then be arranged to call for an emergency brake application should the required speed be exceeded at any point. This is effected by feeding a signal from a speedometer into the circuit and if an automatic brake application does occur the driver is able to regain control of the brakes once the speed has dropped below the permitted limit. Until now, well-tried electric relays have been used in the locomotive circuitry but the first solid-state circuits are on trial to carry out the various functions.

Where intermittent cab signalling systems have been widely applied, as in Great Britain, France and Germany, continuous cab signalling has not as yet

been taken up. It has had considerable application in the United States (where by law trains not fitted with a cab signal must not exceed 80 mile/h) and in Europe it is used by such countries as Holland and Italy. In Holland a few years ago there was a scheme to bring continuous cab signalling into use on every railway in the country, but since then it has occurred to the authorities



Continuous cab signal above driver's console, ETR300 'Settebello' class, Italian State Railways

that track circuiting all the branch lines would cost an inordinate number of guilders without any prospect of a return on the money and branches have been eliminated from the plan. Similarly, in Italy continuous cab signalling is to be confined to the trunk main lines, lesser main lines are being equipped with an intermittent system and other railways will get along without any cab signalling at all. In short, cab signalling systems must pay their way in terms of increased flexibility of traffic flow and the level of the traffic flow determines the system applied or the lack of it—unless as in the United States meddling national legislatures get safety bees in their bonnets and pass laws which do not necessarily increase safety.

In this account of cab signalling mention has been made of emergency brakes automatically applied should a driver disregard a signal to slow down. Such braking is considerably more violent than a normal service brake application and is unsuitable for making routine stops. Braking for routine stops can be done by a machine known as a braking programmer, which was first applied in 1964 to the trains of the new Tokaido line in Japan, the first line of the Shin Kansen or railway network. The multiple-unit trains on this

line regularly have to be stopped from speeds between 100 mile/h and 130 mile/h. Braking is initiated by picking up the appropriate track circuit code and the programmer continuously compares the actual rate of braking with an ideal braking rate curve in its solid-state circuitry. Should the actual braking rate lie outside the ideal curve the programmer automatically increases the braking power applied to the wheels. The track circuits on the line are so sited that every stop is made over the same nominal distance, the actual distance of course being shorter if the line is running uphill. The final stop is made by the driver from a very low speed to ensure the exact placing of the train where required. The Italian State Railways has recently equipped three of its high-speed multiple-unit trains with braking programmers (the *Settebello* train sets) but as the chief signalling engineer wryly observes, 'braking programmers are expensive'. It is probable that in Italy only those trains that regularly go above 112 mile/h in ordinary service will be equipped. Like other pieces of railway equipment, braking programmers must pay their way in terms of greater regularity of operation and less wear and tear on the train and the track and these economies at the moment are only realisable at speeds somewhat above 100 mile/h.

The jointless track circuit is another modern development. For reasons explained in Chapter Six, rails are now welded together into the longest lengths possible and the civil engineer disapproves of the gaps called for by the signal engineer for the track circuit insulated joints. Steel rails are comparatively bad conductors of high frequency electric currents and should a current be at a frequency of somewhere above 1,000 cycles per second it will only flow a few feet along the rails. By selecting the right frequency, limits can be placed on the length of a track circuit as required. Jointless track circuits have applications away from cab signalling, but the development of the necessary high frequency techniques does open up the possibility of passing more messages to a moving train, not necessarily through the rails. Track circuit codes previously described must be well spaced for basic safety reasons, there must be no possibility of confusion between one code and another. Not more than four or five pulsed codes can be employed. The Soviet Union Railways is busily equipping the main line between Leningrad and Moscow for new multiple-unit express trains now being built which will run in trains up to 14 coaches long. These trains on receiving the line clear track circuit pulsed code will automatically accelerate to 125 mile/h and stay there, unless a different track circuit code is picked up. Now of course between Leningrad and Moscow there are curves and stations through which a speed limit must be observed. These speed reductions will be enforced by signals to the train from 'beacons' sited between the rails, the high frequency signal to the train will cause the induced signal in the train's circuitry to cut the train's speed to the required value for the required distance. On a normal run all the driver will have to do is to press a button to start the train at Leningrad and to brake the train from a low speed to stop at Moscow. It should be added that the beacons will be sited a sufficient distance from the speed restrictions to allow gentle braking. Should the train be running late the driver will be able

to take charge and approach the speed restrictions at high speed before braking hard, thus gaining a minute or two on the schedule.

With the control of wide areas of railway from a single signalling installation coupled with the automatic control of the train's speed and of its braking, this chapter is approaching the theme of the next, Automatic Train Operation. In this chapter the safe working of railways has been set out and the widespread use of automation enlarged upon. To enlarge on automation once again, in Great Britain it is proposed to control 5,000 miles of trunk railway route from only 60 signalling installations and in Sweden 3,000 miles of less complicated main line will be controlled from only ten. Automation is paid for by the great decrease in labour employed, a decrease so great that a handsome contribution is made in most cases towards decreasing the general working costs of the railway.

CHAPTER FIVE

Automatic train operation

Because of its carefully controlled environment the railway is far more susceptible to automation techniques than its main road and air transport rivals, indeed full automation is possible. Automatic train operation allows savings in power consumption, promotes smoother conduct of train running operations and makes for substantial savings in wage costs. In previous chapters it has been shown that automation has gone far in both traction and signalling and now in the 'seventies the fully-automatic non-specialised railway is more than a possibility, it will probably come into use. Non-specialised because automatic lines of sorts have been built for many years. At the Wembley Exhibition of 1924-25 in London, the Never-Stop Railway served the exhibition grounds, a double-track straight run through with a turning loop at each end. A screwed drum revolved the length of the line between the rails and an arm from the unmanned passenger cars engaged with the screw. On the open line the screw drove the cars at 20 mile/h and at stations the pitch became very much finer, so that speed dropped to a level at which passengers could step on and off the train as they pleased. The Post Office Tube Railway opened $6\frac{1}{2}$ miles in London between Paddington station and the mail sorting office in Whitechapel in 1926, serving other rail stations and sorting offices intermediately. The line carries mail bags in unmanned cars and is still in service. The trains are controlled by the traction current, which is held at 450 V d.c. in the open line for a speed of 35 mile/h. Should a train be required to halt at a station (on a loop intermediately) the same lever that sets the points drops the approach section traction current to 150 V and thus cuts the train speed to 7 mile/h. The train enters on a dead traction current section in the loop, a relay drops out aboard and springs pull on the brakes for the stop. To start, the signalman energises the loop at 150 V, the relay pulls the brakes off and the train moves out of the station, to encounter 450 V on the main line for full speed.

The New York subway Times Square shuttle which runs to and fro over $1\frac{1}{4}$ miles was automated in 1964. The speed of the train is regulated by picking up the appropriate track circuit code, while a speed and distance regulator measures off the distance run and stops the train at the platforms at each end. A man rides in the train and gives the signal to start. Another United States

railway for the carriage of ore opened in 1964 and is fully-automatic in operation, even to the loading and unloading of the wagons. The Carol Mine trains operate a merry-go-round service and speed is regulated by track circuit codes, which provide for a very low speed at the terminal loops where the loading and unloading is carried out. The Swedish firm ASEA is currently equipping a very similar automatic railway for the Henderson Mine in Colorado, with a more sophisticated means of control. The railway is 14 miles long, includes a ten-mile tunnel and is electrified at 1,400 V d.c. Speed control and braking signals are given to the locomotives by inductive pick-up from a cable that runs the length of the railway, according to a train speed programme. Additionally, the line is divided into sections which are marked by vibrating reed switches alongside the track. A magnet at the front and rear of each train actuates these vibrating reed switches which superimpose their danger signals on the train speed programme to the rear of the moving train. At the automatic loading and unloading points trains will be moved at first by signalman's radio remote control, but it is proposed to automate this operation eventually. Data processing equipment on the locomotives will give the chopper-controlled traction motors or the regenerative brake commands as necessary.

The RATP organisation that runs the Paris Métro made automatic train control experiments as long ago as 1950, but it was not until 1965 that Line 11A was so equipped. Lines 1 and 4 were subsequently equipped in 1971 and 1972. Line 11A was provided with a single cable laid along the sleepers between the rails which carried a 150 c/s current, the cable being switched at right angles from side to side at intervals. The current is picked up inductively by the train which is thus able to detect the cable crossings from side to side. When the crossings are widely spaced the traction motors are powered, a closer spacing and the train coasts and very close spacing applies the brakes. By these means stopping at platforms is within about plus or minus seven feet. For Lines 1 and 4 improved stopping performance was required as the trains are the same length as the platforms. A double-track cable was devised, fed with current at 4,000 c/s. Solid-state circuitry on board adjusts braking effort to obtain a standard deceleration rate and by these means a stopping performance of about plus or minus two feet is possible. An interesting feature is that the current frequency can be adjusted upwards to reach 8,000 c/s, with the effect that all the trains on the line are speeded up. In both systems a driver opens and shuts the doors and pulls a lever to start the train. He can take over manual driving at any point should he so wish.

A really extensive automatic railway opened in London in 1969, the Victoria Line, a 'tube' railway $10\frac{1}{4}$ miles long (since extended by $3\frac{1}{2}$ miles in 1971) with 12 stations. Some of the stations are equipped with crossovers for train reversals short of the terminus. Trains are controlled by a safety track circuit system and an independent braking command system. All running lines are track-circuited and unless a train is picking up one of the track circuit codes of 180, 270 and 420 pulses/min, it can only be driven manually at under 10 mile/h. A man on the train presses a button to start the train

and provided the 420 pulses/min code is being picked up the train will accelerate to maximum speed. Should the train be required to stop between stations (there are no lineside signals for such stops) it will pass on to a 180 pulses/min track circuit which only permits a maximum speed of 25 mile/h. Before this it will have passed a high frequency command 'spot' in the rails. These command 'spots' are of such frequency that the current only spreads along the rails for a distance of up to ten feet. The first command 'spot' is at 15 kilocycles per second (kc/s) and is superimposed on the coded track circuit. When picked up by a train it will cut off power to the motors and allow the train to coast. A second command spot at 20 kc/s applies the brakes and the train stops on the 180 pulses/min track circuit, it not being vital to stop the train at an exact place. When the track circuit changes to 270 pulses/min the train will re-start automatically, this track circuit also only allowing a maximum speed of 25 mile/h. Coasting and the 25 mile/h speed limit track circuits are used to slow the train to pass through crossovers.

Stopping the train at a station is a more precise operation and it is effected by the use of brake command 'spots'. These are arranged as required along the rails so that a 3 kc/s 'spot' will brake a train travelling at 30 mile/h, a 2 kc/s 'spot' from 20 mile/h and so on. The last 'spot' is passed when the train is travelling at about 4 mile/h and provides for a slight release of the brakes so that the final halt is without a jerk. Should a train pass over a 'spot' at a speed over 20 per cent less than the 'spot' is provided for there will be a release of the brakes. By these means a train can be stopped at the desired place alongside the platform within plus or minus five feet. According to the number of people on the train the actual braking effort required will be greater or less as the train weight varies. The braking rate selected is determined by a device known as a mercury retarder, which has been used by metropolitan lines to control braking effort for a good number of years. This consists of a semi-circular glass tube with mercury in the bottom segment covering an electrical contact. The device is mounted on the longitudinal line of the train and when braking commences the mercury will tend to surge up the forward limb of the glass tube, covering first an additional electrical contact and then if the braking is hard enough still another electrical contact. The current flowing through the mercury as a result of completing an electrical circuit in this manner is used to cause the electro-pneumatic brake to slacken the braking action in two stages. The Victoria Line trains have many other features of note, all that is being attempted here is to give a brief description of how they can be made to run without human aid.

The self-driving trains of the Victoria Line are supplemented by a signalling programme machine which signals the entire line for one day's operations. These programme machines have been used to signal a number of London Transport railways since the second world war and work in principle on the lines of the old-fashioned pianola, a machine piano player. In pianolas it will be recalled a long sheet of paper was passed from one roll to another over a bar in which there were a quantity of orifices, one for each note in the piano. Holes were punched in the paper and when one of these holes passed over an

orifice the corresponding note was played by compressed air. If one considers the actions of a signalman operating to a precise railway timetable in a route relay signalling installation, it will be appreciated that the timetable constrains him to push his route setting buttons in an exact order. So London Transport punches a plastics 'pianola roll' with holes according to the required timetable and as each hole is 'played' by the programme machine during the day the corresponding route relay button is pressed and a route set up for a train to run. Signalling can be taken over manually at the control centre should events so require.

It will have been noticed that the trains of the Victoria Line are started by a man in the train pressing a button, actually two buttons to guard against the results of accidental pressing should only one button be provided. The man is on the train primarily because the trains run through constricted single-bore tunnels and if anything goes wrong a halted train can only be got at by walking down the tunnel. In such circumstances London Transport considers it essential to have a man on hand to reassure any passengers who may be marooned in a faulty train. One of the difficulties of automation is that the sort of bright and resourceful man required to deal with emergencies becomes bored stiff when riding about in a train all day with nothing to do. For this reason London Transport has arranged tasks for the man to relieve his boredom; he opens and shuts the doors of the train at stations and presses the buttons to give the train the signal to start. Both jobs might equally well be done by a man on the station platform or for that matter by the programme machine at the control centre.

The 'tube' railways have long sections that run in the open air and London Transport runs trains in double-line tunnels immediately under the surface on the District and Metropolitan Lines as well. London Transport is now considering running automatic trains on both these types of railway with no railwayman on board at all. In case of a stop due to a fault the trains can be got at fairly simply and thus it is considered that the passengers can be safely left to their own devices. But London Transport has qualms about unmanned trains. Its Managing Director (Railways) has written: 'Are Underground users ready to accept them, even with the reassurance that such trains would have built-in equipment specially designed to deal with failure conditions and to get the train and passengers safely and quickly out of tunnels and to a station in an emergency?' So there is doubt in this respect and perhaps elsewhere too, for other metropolitan railways are approaching the same decision. Nevertheless, London Transport is going ahead in developing the unmanned train. I am old enough to remember the fuss there was when air-operated automatic doors were introduced on London's underground railways. People wrote furious letters to newspapers complaining about the dangers of being trapped between moving door panels and anticipating disaster to themselves if there was a railway accident while they were 'sealed into a tin can'. Today no one gives automatic doors a second thought and undoubtedly unmanned trains will reach the same haven of public disregard eventually, once the first storm from the do-nothings, stick-in-the-muds and self-publicity hounds is weathered.

In Japan a Tokyo metropolitan railway is also equipped for automatic operation in the same general way as the Victoria line, the 20-mile Tozai Line, opened in sections from 1964-67. There was a snag in Japan, for the law states that two men must accompany each train and the trade unions were unwilling to see the law altered. So pretty signal lights have been erected to amuse the drivers, although they are discouraged from actually driving the train because automatic train operation promotes smoother running of the railway and saves traction current. From observation it appears that the Paris Métro automatic railways previously described may have run into trade union trouble too. It was seen that a pair of men are carried in the front of the train, one to open and shut the doors and the other to pull the lever to start the train. Another line considering unmanned operation is the Circum-vesuviana Railway at Naples. The railway is highly automated with continuous track circuiting, supplementary jointless track circuits and automatic braking. Given a little extra apparatus driverless trains will be possible. The railway is single-track for the greater part of its mileage and these single-track sections are already being operated automatically. A train closing the appropriate track circuit at one station causes the interlocking at the next station to be interrogated for the onward movement through the section. The interrogated interlocking automatically checks that the track circuits in the section are clear, if necessary reverses the signalling and track circuits for the direction of travel desired and finally clears the signals for the train movement.

An extensive 75-mile metropolitan railway network called the Bay Area Rapid Transit opened in San Francisco in 1972, after years of research and development work. It is an automatic train operation railway right down to the opening and closing of train doors at the stations. The trains carry drivers, but apparently they have no duties except to take action in case of emergency or failure. The control of the railway is by computer rather than by programme machine. When computers became popular they were at first looked at rather askance by the signalling engineer. An interlocking signalling installation is after all merely a specialised form of computer (even the first interlocking installation at Bricklayers Arms of 1846 could perhaps be roped into the computer definition) and signalling engineers rightly felt that they had been designing computers for years, rather elementary computers but computers nevertheless. They also asked awkward questions about reliability, such as 'how many years will a computer function without a fault?' Computer manufacturers, who congratulate themselves if all systems are go in a moon rocket for say one month, were taken aback at first. Nevertheless, the manufacturers can supply equipment with obvious signalling applications and both sides are now shaking down together to work out common problems. Bay Area Rapid Transit has set up a centralised train control installation which is equipped with three computers. One will be programmed with the timetable of the day and will carry out the signalling functions and train operating requirements throughout the system, the trains running to within plus or minus five seconds of the booked time. The second

computer will be similarly programmed and will back up the first, ready to take over should the latter become faulty in any way. The third computer will be in reserve for maintenance and programming. Signalmen are turned into computer programmers and one will watch over the operating computer to pick up and deal with any incidents for which it is not programmed, although when programmed the computer will be instructed on what to do in the event of various emergencies.

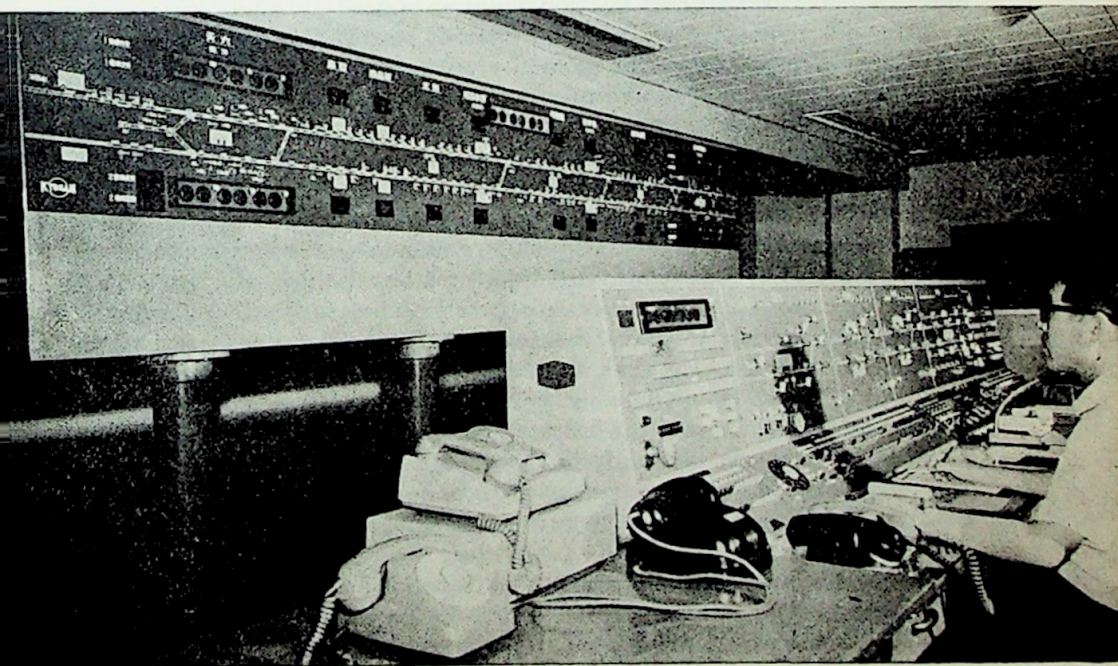
Computers are already in use for railway operating duties, with a view to saving labour and cutting costs on the one hand and smoothing train running operations on the other. In Great Britain there is a computer programmed with the day's timetable at the Glasgow Central terminus, including all the platforms the trains will use. Approaching trains are advised from outlying signalboxes by train describers and should a train arrive late the computer recasts the timetable, complete with platform alterations, and presents the results to the signalman. The signalman if he wishes can feed in other information not known to the computer and the computer will present him with a revised timetable in the light of the extra information. An earlier installation is sited at Leeds, where for some years it has been deciding precedence of trains over the complicated network of railways at this centre. British Rail does not always plump for computers. A very busy small manual signalbox exists at Borough Market Junction outside London Bridge station, where a mistake in signalling a train can upset train services over a wide area of south-east London. A study was made of the possibilities of carrying out the signalling by computer, but the conclusion was reached that a computer would show no operating advantages over the skilled signalmen at present in charge. Nevertheless, work is now under way to merge the operations of this signalbox into a route relay signalling installation which will control a wide area.

These British computer installations do not actually signal trains, but the Swedish State Railways is now using computers for this more vital purpose. The ever-growing traffic at Stockholm can only be accommodated on the railway network of the city (together with some main line trains) by strict control and from 1970 some 60 signalbox interlockings were operated from a new centralised train control, a quantity of interlockings that will go up later to around one hundred. Two computers control the interlockings and are themselves controlled in turn by the push buttons of the centre. During 1972 it was the intention to instal a third computer, which will be programmed with a complete day's timetable and which will control the other two computers. Each of the existing computers has a capacity of 36,864 railway indications and electronically communicates with all the interlockings under its control in four-second cycles, sending out commands and receiving information in confirmation and for the illuminated track diagram. While each computer supervises the whole area, in normal working one computer sends out commands for the railways of north Stockholm and the other deals with the south. In the event of the failure of either computer the remaining one will take over the whole load automatically. In the last chapter

mention was made of the solid-state centralised train control that directs the operations of the Milan Metropolitan. Distinguishing between the circuitry of this latter 1964 installation and that of the 1970 installation at Stockholm would be difficult, except that the Stockholm installation is considerably greater in size. Computer in short is merely a fancy word to describe a modern electronic signalling installation. In view of the reaction of many members of the public nowadays to the dread word computer, perhaps it would be better if railways stuck to the term signalling installation, or perhaps used the less emotive words data processing unit. Incidentally, the Swedish State Railways has begun the replacement of the well-tried electric relays by solid-state switches in some of its Stockholm interlockings, with successful results.

During 1972 the German Federal Railway brought into use the first sections of railway to be controlled by a timetabling computer, part of a scheme to control over one hundred route miles of line comprising the network in the Saarbrücken area. The installation can be taken to be the prototype of the centralised train control timetabling computers mentioned later in connection with automatic train operation of driverless trains. The computer in the full scheme (with suitable stand-by backing up) will control 40 route relay interlockings and eight junctions. Trains will enter the controlled area from 20 railways or yards, such entries being reported to the computer by the border station signalman. Similarly, border station signalmen

Controller at the console of the timetabling computer which automatically signals and supervises the Osaka Subway



will be advised by the computer of trains approaching them from the area. The computer will be programmed with the day's timetable and will signal for this as the trains are advised. Should a train enter the area late, the computer will analyse the situation and automatically recast the timetable for the optimum running of all trains. Certain stations require the running lines for shunting operations and the yardmaster will request the computer to allow the movements required, which will be fitted in when the timetable allows. Owing to the complicated network and the number of trains likely to be moving through it, it is considered that a human controller would be unable to take in all the information offered by an illuminated track diagram. The diagram is omitted at the centralised train control and when the computer meets a situation for which it is not programmed it will print out its difficulties for the controller's action. Similarly, failures of apparatus are also printed out, together with statistics. Should the controller require to run an extra train outside the timetable, before setting up a pathway for it in the computer he can ask the computer what delays will occur to other trains for various alternative starting times and the computer will print out the information. Among its other activities this computer may also be arranged to set the points for the sidings as successive batches of wagons roll down by gravity from a hump in the Saarbrücken marshalling yard.

It will have been noticed that all the automatic railways so far described, or railways approaching full automation, are characterised by regularity of traffic flow and of train composition, that is that while trains may vary in number at different times of day they all move at much the same speed and make up to much the same load for each traction motor or braking device. It is otherwise on main-line railways, trains move at various booked timetable speeds and differ greatly in gross weight, locomotive power and braking characteristics. From the point of view of control by timetable the problem is complicated by trains that do not run every day, special trains and other demands that call for out of course running. Problems in providing an automatic train operation therefore become very complex indeed and correspondingly costly. Indeed, the problems may be insoluble in the sense that costs may be so great that it would be commercially out of the question, without some rationalisation of the present diversity of train services to simplify matters. Fortunately, commercial pressures on railways as businesses are already leading to the simplification of many of the services offered. In some countries branch lines, local goods trains and stopping passenger trains have all but vanished and train speeds are being brought closer together as every customer (both passengers and owners of freight) demands the fastest transit time possible. Some automation on main-line railways is already in existence, full automatic train operation will be possible for many sections where economically viable (the matter has only reached the experimental stage as yet) and a great deal more automation will certainly be applied.

British Rail is currently developing an inductive cab signalling and train control system for automatic train operation, based on an electric current flowing in a pair of wires about two feet apart and laid on the railway sleepers

between the rails. The wires are crossed from side to side over each other every 100 metres, the transposition allowing the train to determine its position on the line as the reversal of the magnetic field that occurs can be detected on board. British Rail does not propose to develop the system to allow driverless trains at the present time (except in one special case noted in Chapter Six) but its activities are interesting as they demonstrate how such systems must be broken down into stages of advance. The first stage must be compatible with existing signalling and each subsequent stage must build on the equipment already in existence for the previous stages. The present British system of intermittent cab signalling can show if a warning signal is a caution or clear only, whereas the lineside signal can show two degrees of caution and the warning indications may be displayed at a signal that also has a stop aspect when required. It is desired to give the driver a cab signal corresponding to each of the lineside signal indications. At the first stage a 250-yd long pair of wires was laid as a loop at the approach to each signal. In the wires a 48 kc/s current is pulse-coded according to the signal indication, picked up inductively by the train, decoded and used to operate the cab signal. The driver must acknowledge signals to slow down or automatic braking occurs and train stops are installed at stop signals (similar to those of London Transport, described in Chapter Four) to apply the emergency brake should the train pass the signal. The cab signal is displayed even after the signal has been passed until the next track pair of loop wires is encountered. The apparatus can be used in conjunction with the existing intermittent system of cab signalling, that is the same train can operate over both systems. This new system of cab signalling has been installed over various sections of line in the Southern Region.

The second stage is a speed supervisory system which requires the installation of two small computers in the locomotives (the computers together disposing of 360 integrated circuits) as well as the extension of the track pair of wires the entire length of the railway controlled by each signalling installation interlocking. Before the train starts the train-borne computers are programmed (by means of a punched card) with the train's unique number, its length, its maximum permissible speed, the brake release time, the braking rate and the train's category. Information is conveyed to the train from the track wires by a 65 kc/s carrier wave which transmits an electronic telegram giving information on the distances to the next four signals and the average gradients over those distances, the next four speed restrictions, the distances to their commencement and the average gradients over those distances, the present speed restriction and the distance from its commencement, together with information on the route and the location of the section end. The information is derived from lineside electronic memory units, which are designed so that additional information can be fed into them to give permanent way repair speed restrictions and to provide for subsequent alterations of track layout. As an upshot of all this information, which is processed on board, the driver is provided in addition to the cab signal displays with information on the maximum speed permissible and the maxi-

imum speed permissible ahead of the train, together with the distance to be run until the speed ahead is in force and another distance figure giving him his location. This equipment is now being tried out on a length of line through Wilmslow near Stockport.

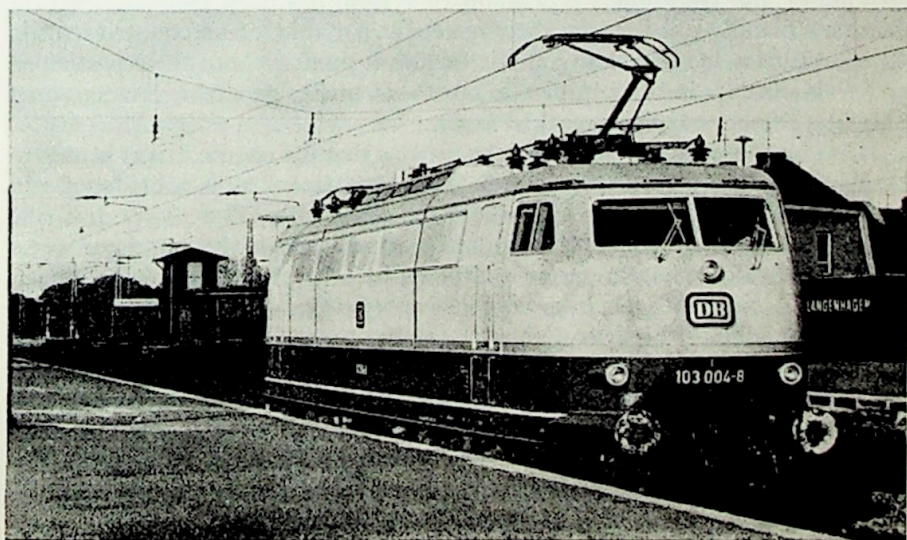
Future stages will provide for a telephone between the driver and the signalling installation (for calls initiated in either direction) and for the transmission of extra data to and from the signalling installation. Experiments will be made with the telephone at Wilmslow. This will use the same pair of wires in the track as will the extra data transmission stages. The extra data will be used in timetabling computers at the signalling installations, the computer at Glasgow Central station mentioned a page or two back is the prototype of these computers. Inward data will give the computer a much more exact idea of the position and speed of the train, while outward data will no doubt contain such things as an instruction to the train to slow down should it be approaching a junction point too quickly to mesh in with other trains. All this cab signalling and automatic train operation equipment will be over and above the normal track circuiting and signalling equipment and the signalling engineers are naturally concerned about the cost. They are calling on the manufacturers, for example, to produce the train-borne computers that they require for less than £2,000 each, possibly at a price of not above £1,000. Even so, the apparatus will be expensive and it may be possible to equip only the most heavily used sections of railway with the full automatic train operation envisaged, less busy sections will have to make do with stage two described or even stage one. Over in Germany the German Federal Railway is also developing an automatic train operation system, but it is going the whole hog. For the past two years it has had one of its large 103 class express locomotives running experimentally from time to time with no driver on board at all between Hanover and Uelzen, a distance of 36 miles. Unmanned trains will perhaps allow the Germans to talk turkey about costs, for eliminating the wages of the driver and his helper will offer large savings. The Germans have an incentive for unmanned trains too, the wage element of their railway operating costs amounts to 70 per cent compared with 62 per cent for British Rail.

The German Federal Railways automatic train operation system has two wires laid on the sleepers transposed at 100-metre intervals just as in Britain, and these wires are continuous for the whole section controlled by a signalling installation. The signals to and from the wires are passed inductively and each locomotive is fitted with solid-state data-processing circuitry (the German Federal eschews the term computer but the circuitry amounts to the same thing). The data processing circuitry composes electronic telegrams which are continuously transmitted to the signalling installations, the telegrams containing information on the train's position, speed, its telegraphic address number, its braking characteristics and so on. The signalling installations in German practice are seven or eight miles apart and data processing circuitry at each receives the telegrams from all the trains in its area and also collects data on the commands of the signalman, position of track circuits, position of

signals, position at level crossings and so on. All this data is processed and a continuous stream of electronic telegrams is dispatched, each part of a telegram prefixed by the address of the train to which it refers. The information in both the ingoing and outgoing telegrams is of course continuously updated as the positions of the trains in the charge of the signalling installation change.

Basically, the train requires an instruction to proceed at a certain speed and this information is supplied to it by the telegram from the signalling installation. Should the train be manually driven this must be supplemented by cab signal information, the future speed required and the distance to the start of this speed requirement, warnings about unprotected level crossings and so on. Additional information is passed as well, in the case of the driver being told to slow down additional lights will tell him why, station stop, permanent way repair slowing and so on. For unmanned train operation the required speed signal will suffice in most cases, the lineside data processing equipment having previously determined that the line is clear for at least double the distance in which the train can be braked to a stop. For express trains at 95 mile/h this double braking distance amounts to about three miles, but as the speed diminishes the distance will shrink, at walking pace it will be scarcely more than a number of yards. The increased train working flexibility offered by unmanned operation will be appreciated, indeed the same flexibility is offered in manned operation provided that the driver acts only on the cab signals and does not look for confirmation of their indications by lineside signal on every occasion. As a bonus in unmanned operation, once it is established that all trains will be unmanned, most if not all the lineside signals can be dismantled together with all their associated circuitry. It is a railway operating

Automatic train operation, German Federal Railway. Trial unmanned 103 class electric locomotive passing an intermediate station between Hanover and Uelzen



revolution, for the long established practice of dividing up the line into sections and only allowing one train into each section at a time is abolished. In effect each train will carry its own section about with it, the length of the section varying with the train's speed. The automatic train operation data processing equipment in the signalling installations will ensure that these portable railway sections do not clash.

Comparing the British automatic train operation system previously described with the German system, it will be seen that the British rely more on the train-borne data processing equipment to control the running of the train, whereas in Germany it is the signalling installation equipment that does most of the work and issues the necessary commands. The British system will require extra data channels should timetabling computers be installed to regulate trains, whereas the German system is complete in itself. Should timetabling computers be installed in German centralised train controls, they will issue their commands to the signalling installation data processing equipment, all the extra equipment needed will be outside the present experimental installations. It should be noted that the British system, just as the German, permits the abolition of the present railway sections at stage two as described, in Britain too trains will be able to run carrying their portable railway sections about with them although the constraint of lineside signals will still exist. Automatic train operation systems based on similar electronic techniques are being developed in Belgium, France and Russia as well, but the details in all cases differ just as the British and German details differ. This may be a source of trouble in future, for trains run through between country and country and the expense of such through running will be greatly increased if the motive power has to be fitted with apparatus for several control systems. International conferences have been held on automatic train operation, mainly for the exchange of technical information and techniques, but the subject of a standard system has been touched on. The Germans blandly put forward their system as suitable for all countries while other countries hammer away at the technical points where their particular system is superior in their opinion to all others, but no general agreement on a universal system has been reached as yet.

It has been indicated that one of the reasons that the engine driver is now to be eliminated from the railway scene is his cost, but if he is considered as a machine there are other reasons why he should go. The driver has one enormous advantage of course, as a data processing device he can digest great quantities of diverse information and come up with the right answer almost every time, especially when he is in charge of a train and knows that he is likely to be killed if he does not get the right answer. Nevertheless, with the increasing speed of trains it is to be noted that this advantage is being whittled away, the driver simply cannot record and act upon all the information that he is required to note because it is offered to him too quickly. On the other hand the driver gets tired during a turn of duty and his performance lessens. His attention can be readily distracted from the job in hand; a remark by his mate, wondering if his dinner on the locomotive's hotplate is ready or the

sight of a pretty girl he is passing. He suffers from indigestion which divides his attention too, at rare intervals he gets heart attacks or otherwise falls ill and he is prey to plain human mistakes, as the driver of an empty London Transport 'tube' train who ran full speed into a tunnel (apparently while reading a book) to get killed when the train hit the buffer stops because it was a siding tunnel and not the main line. The railway is a highly artificial environment and because of this all the various things that can happen to a train can be controlled. Because of the high degree of control the data to be presented to a machine which takes the place of an engine driver are limited and within the machine's capacity, the superior data processing capacity of the driver is not really needed. A machine is more reliable than a man and when it fails it can be made to fail safe; a driver's failings are so various that it is difficult to guard against all of them satisfactorily to maintain safety. Safety is basic to railway operations and when unmanned trains come into general use a great point in their favour will be the increase in safety thus made possible.

Returning to the German automatic train operation apparatus for a moment, telephone communication can be established with a moving train just as in the British system. But if the train is unmanned why should a telephone be required? Here we run into a current matter of discussion, for a great many railwaymen are convinced that trains cannot be allowed to run about on their own without someone aboard to take charge in case of any fault, failure or accident. Maybe freight trains can be unmanned they say, but passenger trains most certainly cannot be. The argument then goes on to claim that the driver must be retained on passenger trains to provide the necessary man on the spot. The trouble is, what is the driver to do all day? For except in emergency it is undesirable for him to touch the controls lest he upset the smooth working of the railway and because of the probable increase in electric current or diesel fuel consumption that this would lead to. It is the old problem of automation, how to occupy the necessary man who deals with disaster while he is waiting for disaster to turn up.

As a purely personal answer to the problem of the man on the train it is pointed out that one railwayman rides on nearly all passenger trains, the ticket collector. It is true that in Great Britain a great many trains get along without him, because railway platforms are guarded by gates where ticket checking is done. On a number of other European systems the gates have been abolished and all ticket inspection is carried out on the train, often a number of ticket collectors is present on each train. The ticket collector then is the man on the spot, already trained in railway rules for safety reasons and available to deal with automatic train operation faults. At the very least when he suspects that something is wrong he can telephone the signalling installation and ask 'why have we stopped?'. He could also be trained to drive the train at, say, not more than 10 mile/h subject to an automatic brake application if he exceeded the speed limit; this would suffice to get himself and his train out of any hole that they happened to be in. Furthermore he would be very usefully employed between emergencies in checking tickets. One of the things that any worker in transport of whatever type learns fast is that most passen-

gers will cheat on the validity of their tickets once they think that they are not being watched. Moscow tramways are perhaps the only organisation outside this proposition. In Moscow in 1968 the tram conductor and his tickets were abolished. The boarding passenger is trusted to drop the necessary number of kopecks for his flat rate fare into the box provided. Apparently in Moscow if the boarding passenger does not drop kopecks into the box (or at any rate drop something in) the rest of the passengers in the tram point out the error of his ways at the tops of their voices—especially the women. The Muscovite tramway authorities report in 1971 still claimed that they were making a profit on the deal, but Moscow is very much an exception to the general rule that income diminishes if the passengers are not watched.

Reference has been made in this account to new timetabling computers at San Francisco, Saarbrücken and at Stockholm, but timetabling computers have been in operation in Japan. Lines 1 and 6 of the Osaka Subway have had them in operation for the last year or two. Line 6's computer automatically selects the right timetable for the day of the week and signals for it throughout the day. In addition it operates the control centre's illuminated track diagram (displaying on it as well the departure time and destination of the next train from the terminals), the power control centre's modified illuminated diagram, train destination indicators at all stations and a timetable print out, as well as collating statistics and printing them out. The computer is programmed to handle some out-of-course operations if they arise, but the controller takes over for manual operation should anything happen that is outside the scope of the programme. The lines are only out and home railways but some trains do reverse short of the final destination. Timetabling computers will be economic only where there is a regular service of an intense nature, in all probability. British Rail's Southern Region is currently halfway through a scheme to reduce its 485 signal boxes to 13 signalling installations. The greater part of this region's traffic is passenger and of an intensive suburban nature at that. One can envisage that equipping the 13 signalling installations with interconnected timetabling computers, coupled with automatic train operation of driverless trains, might make a startling cut in the region's operating expenses—perhaps there would be some money left over to cut fares, the cost of which seems to preoccupy many of the passengers.

Years ago the job of signalman was one for a steady and reliable man who could be trusted to carry out all the rules and regulations to the letter on every occasion, and who in addition had the necessary physical strength to pull over the levers of a mechanical interlocking frame. Now no physical strength is needed to push a button and while rules and regulations must be obeyed they no longer have a safety significance. Signalmen's errors can make a muddle but they no longer endanger people's lives. Safety is now the province of the signalling engineer and his men, with the great advantage that an action of any of them in the drawing office or in wiring up on the ground can be checked quite independently before the work is put to use, unlike the work of the old-time signalman. Signalmen must now be mentally alert, ready to assess a rapidly developing situation as shown to them on the illuminated

track diagram and be in possession of the knack of quick, correct decision. A knowledge of computer operation techniques must also be acquired. In short it is suggested that it is just the field of action for a management trainee aspiring to be a railway operating manager, for a few years in signalling installations would teach him most effectively what it is all about. Without being able to hold out the prospect of wider-ranging responsibility as a man gets older, together with the higher pay that that implies, railways might have future difficulty in recruiting men or women of the right calibre for signalling.

In this chapter on automatic train operation an endeavour has been made to present the salient points, but inevitably not everything has been covered. Many people who know something about railways will have questions, typically beginning 'yes, but what happens if . . .?'. To them it can only be said that the systems described have been designed by railwaymen and that no doubt all eventualities have been foreseen. It should be noted by-the-way that automatic train operation links up with full automation on board locomotives as described in Chapter Two. The driver on a fully-automated locomotive is presented with two controls, one to go faster and one to go slower. These controls when operated regulate the value of an electric current and this current can be regulated just as easily by signals from a train-borne computer or data processing unit (that is in turn picking up signals from the ground), as it can be by the movements of the driver's hands. Automatic train operation saves wages, economises on fuel and power and improves train operation. It will come into use on main lines in the near future wherever economics permit and the spread of the techniques has already been started on metropolitan railways. Once again, railway automation will cut costs and lead to cheaper transport.

CHAPTER SIX

High speed railways

The railway was man's first step forward from land speeds offered by muscles, whether his own or those of a horse, and speed has always been an advantage of rail transport. Now it is more important than ever, first to compete with the more flexible but slower road transport mode on the one hand and on the other to retain long-distance traffic when competing with the much faster but less flexible air transport mode. For main-line passenger traffic successful competition is over distances from about 50 miles up to about 300-400 miles at present speeds and at up to about 500 miles at speeds soon to be attained. Within these limits rail can offer superior passenger services in terms of speed, comfort and convenience. There are too the specialised passenger services of the metropolitan and suburban railways, but because of the number of stops high speeds are not generally attained. Accelerated passenger services have clearly demonstrated that high speed pays, the greater the speed increase over the previous service the greater the traffic increase and the greater the revenue, less of course the extra expenses incurred to make the high speed possible. On the freight side too speed pays, but here there is no general objective. Certain traffics can be made to grow by lessening the transit times but with others increased speed does not necessarily bring commercial benefit. Nevertheless, when passenger train speeds are increased the speed of freight trains is increased too willy-nilly, when both types of traffic are using the same railway. To run the maximum number of trains over a given section of railway means that all the trains must run at much the same speed and for this reason freight will be carried at a higher speed on many lines in future.

High speed railways in this chapter will be taken as those railways where a 100 mile/h maximum speed is regularly reached or exceeded. The speed of 100 mile/h was attained regularly by trains in ordinary service for the first time about thirty-five years ago in the United States, Germany and Great Britain. Since that time the United States and Germany have dropped out, only on the New York-Washington run does the Penn Central still reach 100 mile/h. Great Britain, after the setback of the second world war, has raced ahead and with the possible exception of Japan now has more trains that touch 100 mile/h each day than any country in the world, although

100 mile/h is the maximum speed permitted. Both diesel and electric locomotives reach this maximum speed. In other countries of Europe the general maximum speed is 95 mile/h with perhaps a few important trains occasionally touching 100 mile/h. In two special cases 100 mile/h is exceeded, in Italy certain trains on the Milan-Rome-Naples line run up to 112 mile/h and in France two train services and their returns go up to 125 mile/h. In Russia 100 mile/h is attained on the electrified Leningrad-Moscow route. In Japan many trains regularly reach the line maximum speed of 130 mile/h on the New Tokaido line. This last railway was a fresh phenomenon in the transport world, a railway specifically built for high speed passenger services. It runs 320 miles between Tokyo and Osaka with 11 intermediate stations and relieves the Old Tokaido line, which was choked with traffic before the new railway opened in 1964. It was designed for 155 mile/h but various factors led to the dropping of the maximum speed to 130 mile/h in practice; among the factors was the reluctance of the drivers to run fast for they were conscious of their drop in performance at high speed. The high speed railway is helped by the existence of the old railway to take freight traffic and this old line is available also to handle any excess passenger traffic.

The gain in passenger traffic because of high speed and in some cases the gain demonstrated by their own high speed trains, has led many railway administrations to plan high speed lines. In Italy a 155 mile/h railway is actively being built between Rome and Florence and it is probable that stretches of the existing Rome-Naples and Milan-Florence railways will be adapted for 155 mile/h speed. In France plans are laid for a 185 mile/h railway between Paris and Lyons. France and Belgium together plan a 185 mile/h railway between Paris and Brussels, which will be pushed on eventually to Amsterdam and will have a branch through the Channel Tunnel to London. In Great Britain a short high speed line (referred to later) is planned between London and a new airport to be built on Foulness Island. The German Federal Railway has nearly 600 miles of 155 mile/h and 185 mile/h railway planned between major centres. Even Switzerland is thinking of 125 mile/h railways despite its mountainous terrain. Russia is improving the Leningrad-Moscow route for 125 mile/h and has planned a 1,000-mile, 155 mile/h railway from Moscow to the Caucasus area. Finally, Japan opened a 155 mile/h extension of the New Tokaido line between Osaka and Okayama in 1972 and is actively building onwards to Hiroshima and a tunnel under the straits to reach Hakata in Kyushu Island. This is part of a network of high speed lines that will extend for 4,300 miles or so over Japan, known as the Shin Kansen. Other lines of the Shin Kansen are now being built northwards from Tokyo.

Building new railways for high speed is expensive, so is adapting existing railways for high speeds, but some thought has been given to increasing speed on these latter as they stand. A major difficulty is the existence of curves which would call for a speed reduction should maximum speeds be attempted that are higher than those current today. It has long been known that trains can run through curves safely at speeds much higher than they do, an increase

up to 50 per cent is possible. What stops the train running through curves at higher speeds is the effect on the passengers and loose objects inside. I have had experience of what happens for I was a passenger in a special train that reached 114 mile/h approaching Crewe Station in 1937. Running into the station with the brakes hard on but still at high speed the train was inadvertently run through a crossover with a speed limit of 20 mile/h. The speed through the crossover was 56 mile/h and while seated passengers would merely have been alarmed the effect on those standing was not so fortunate. Personally I received the then Chief Civil Engineer of the LMS Railway in my lap (he was a massive man) and his language about the giddy lads of the traction and operating departments as he struggled to his feet was remarkable. Needless to say he did not use the word giddy. Later when the train was at rest at the platform I looked into the kitchen car—the whole floor was ankle deep in cutlery, crockery and food. The locomotive and train were unharmed but men were to be seen at work fettling the crossover later, which had been left not quite as it should be. Trains therefore can run through curves at much higher speeds than they do.

The answer to higher speed through curves as far as passengers and the contents of trains are concerned is known to any motor-cyclist who leans inwards when rounding the curve. The whole coach body must be tilted with respect to the wheels and the bogie frames to give the leaning effect. The Chesapeake & Ohio Railroad built a tilting-coach lightweight experimental train in the 1950s and the French National Railways built an experimental tilting coach in 1957. The North American Turbotrains were also equipped with tilting bodies when they were built in 1965. All these had the tilting body supported from a point near the roof and relied on centrifugal forces for tilting about these axes. In practice the response was too slow and the passengers still received shocks although the shocks were much reduced. A positive power drive was required, which now is usually given by hydraulic rams under the control of electric signals from a sensitive accelerometer, which in turn detects centrifugal forces acting on the coach body. The German Federal Railway was first in the field with a diesel-powered tilting-coach five-unit railcar train in 1968, this particular train being suspended on air-filled bellows. A pendulum made or broke electrical contacts and electro-pneumatic valves filled or emptied the bellows with air to give the tilt as required. In 1969 the Swedish State Railways tried a tilting-body electric motor coach, which was the first vehicle with a non-tilting pantograph to permit the undisturbed collection of traction current. Similar pantographs were fitted to a Japanese experimental tilting-body train set in 1972. The French National Railways has 90 *grand confort* passenger coaches being built that can be fitted with tilting apparatus when required, as can its gas turbine-powered train sets, and the Swiss Federal Railways has three tilting-body coaches on trial. The Italian State Railways had a prototype tilting-body electric multiple-unit train set on trial in 1972. British Rail's Advanced Passenger Train also possesses a tilting body. This last is for very high speeds as is some of the other stock mentioned, but nevertheless it is probable

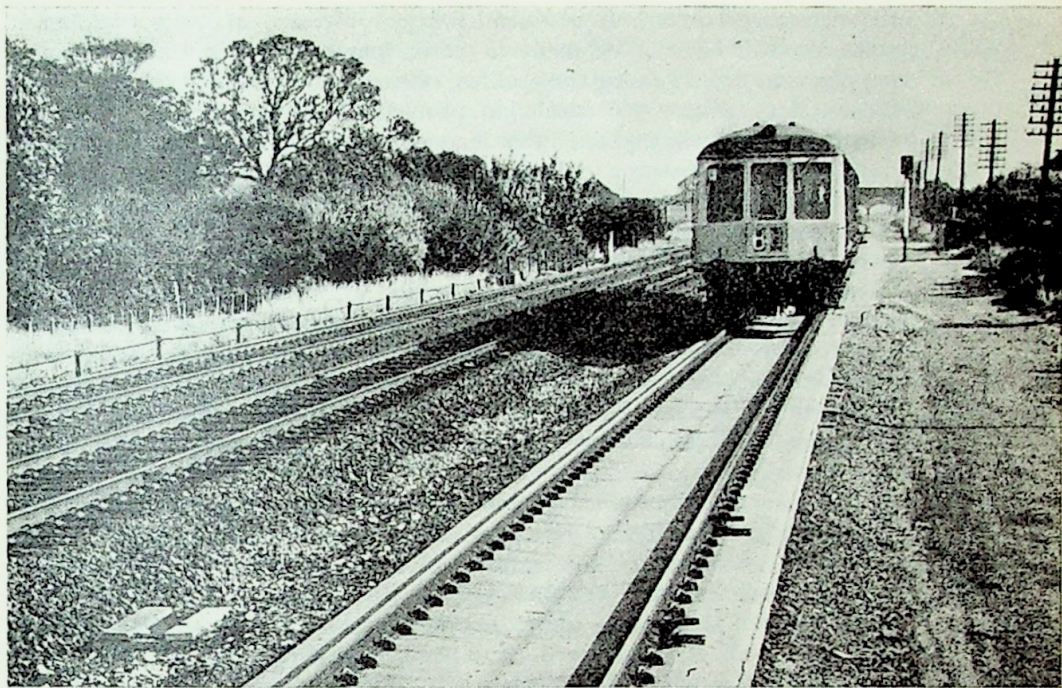
that the chief use for tilting-body trains will be to accelerate train services over mountain railways and secondary lines, routes which either cannot be rebuilt or are not worth rebuilding.

Track design is another constraint on high speed. In Great Britain it is hopefully known as the permanent way, although it is anything but that even under the best of conditions and under high speed traffic it is even less permanent than usual. Its rate of deterioration is determined by the weight, speed and frequency of the trains that run over it. On the British Rail electrified route from Euston to Liverpool and Manchester (maximum speed 100 mile/h) as well as on the New Tokaido line in Japan (maximum speed 130 mile/h) the frequency of trains is high and track maintenance costs have been soaring. Track is now laid with flat-bottom rails of 95 to 132 lb/yd which will allow each axle of a locomotive or vehicle to carry a load of up to 30 tons. In Europe 20 tons is normally the maximum axleload (up to 25 tons in Great Britain) and the higher axleloadings are found on some railways in the United States or on specialised mineral railways. The rails are welded into the longest possible lengths, up to several miles, in order to minimise the number of rail joints which require much maintenance. The rails rest on steel baseplates bolted to the sleeper and to minimise noise and give a softer ride elastomer pads are inserted both between the rail and the baseplate and under the baseplate. The rails are either indirectly bolted to the baseplate or some form of spring fastener is provided, both must be adjustable to take up any slack. Epoxy resin adhesives are used frequently nowadays to secure the baseplate bolts in the sleepers and to hold together the insulated rail joints provided for signalling purposes.

Sleepers are made of creosoted timber or prestressed concrete. Steel is also used, usually in areas where timber deteriorates too quickly and concrete is not readily available. Economics determine the choice between timber and prestressed concrete. In Great Britain prestressed concrete sleepers are standard, with timbers under points and crossings in Australian jarrah. In Italy timber or concrete is used indifferently, while the Dutch find timber sleepers cheapest, mainly because a special type of steel and concrete sleeper must be used to suit their soft terrain. Sleeper spacing affects the load track can carry, in Europe the spacing is just under every two feet while in the United States a closer spacing is favoured. The sleepers rest in a ballast layer about two feet deep and this in turn rests on a sub-ballast layer about one foot deep, the top layer allowing ready drainage and the bottom preventing the penetration of mud and slurry from the sub-soil. Quite often the sub-ballast is laid as a concrete slurry and in very wet situations polythene sheet is laid over the sub-soil before ballasting is started. Track maintenance consists of tamping the ballast back under the sleepers and in keeping the track in its correct alignment and on the correct level. Heavier maintenance includes ballast cleaning as well as sleeper and rail renewal. All this maintenance is done by machinery nowadays and machinery together with modern track design has helped British Rail to cut track maintenance costs over 25 years by a startling 80 per cent.

The track described should have a life of 20 to 30 years, but today's more frequent and faster trains are seeking out its weak points and it is evident that any increase in speeds above today's 100-130 mile/h will make maintenance so costly that any increased profits because of speed might be swallowed up. One trouble is that latent flaws in the steel of the rails now develop into outright cracks and broken rails. Railcars equipped with ultrasonic apparatus now tour the lines to detect incipient cracks in the rails so that the rails can be renewed, the German Federal Railway putting the first of these railcars into service in 1956. All this costs money and the search is now on for a more durable track, especially in view of the higher speeds now envisaged. The answer is known as solid-bed track, in which rails and their elastomer pads (sometimes with baseplates as well) are laid direct on to a reinforced concrete platform which runs the length of the railway. Solid beds in various forms have long been used on viaducts and in tunnels but now experiments are being made for their general adoption everywhere; the German Federal Railway started in 1967, British Rail in 1969, Japanese National Railways in 1970 and the US Department of Transportation in 1971. Two major variations are in use, the first involves the laying of a lean concrete foundation layer and laying reinforced concrete slabs about fifteen feet long on top of this, there being variation in the concrete slab type according to the railway using them. The second method calls for a road-type slip-form paver built for the narrower width used on the railway, which forms a continuous reinforced concrete slab up to the level required all along the line. British Rail is using the slip-form paver, the experiment being supported by the International Union of Railways. Laying the track by these methods will be more expensive but maintenance costs are expected to fall by 20 per cent or more, while the track will be much more durable under high speed trains. The Japanese National Railways has already decided that the Shin Kansen will be laid on reinforced concrete slabs in future, although it is to be noted that this system is likely to run almost throughout on viaducts or in tunnel.

High speed poses problems on electric railways too, not least because faster trains consume more power. Several railways are putting in more electricity sub-stations along main routes to ensure that high speed trains will have adequate supplies. Since the 1930s the transformers and rectifiers at sub-stations have been unattended and controlled from a central point. Today the power control panel is usually sited alongside the illuminated track diagram in the centralised train control, so that the operator can observe where trains will be making power demands. Electronic telegraph control as described for signalling is used for messages to and from the sub-stations and on the New Tokaido line the first power control interlocking with the signalling has been carried out, so that a power failure will have an effect on the signalling. Eventually no doubt timetabling computers in charge of train operations on a whole railway will be arranged to control power supplies as well at the same time. Having got the power into the overhead line there remains the problem of getting it into the train. The overhead contact wire is of copper and is supported at intervals from a catenary cable directly above. The catenary



British Rail solid-bed track, the rails being laid direct on reinforced concrete, with a resilient pad between rail and concrete

cable is of stranded copper, or for economy steel strands can be included or the whole cable can be made of stranded steel and aluminium. Both wire and cable are live and are carried on insulators supported by masts or portals at 200–230 feet intervals. The contact wire and catenary cable expand and contract according to the ambient temperature and the contact wire is tensioned by weights placed every one to one-and-a-half miles, sometimes the catenary cable is tensioned as well. The weights work on pulleys to take up slack as it occurs. The contact wire retains some vertical movement nevertheless and the suitably sprung locomotive pantograph must maintain constant contact to avoid arcing and other troubles, despite the bouncing and rolling of the locomotive on which it is mounted. Some pretty problems in dynamics are involved and some railways are still working out details for new faster locomotive types.

The Japanese National Railways thinks that it has the overhead wire and pantograph relationship solved for speeds up to 161 mile/h, the French National Railways is satisfied that it can run up to 185 mile/h and British Rail thinks it can manage 200 mile/h. Somewhere above 185–200 mile/h difficulties are anticipated, both because of wear and tear and because at such high speeds the power required by the locomotive is so great that the contact area between the wire and the pantograph pan is perhaps insufficient to pass

the necessary current. It is considered possible that above 200 mile/h a reversion will have to be made to third, fourth and fifth rails for power supply, thus greatly easing the problem of current collection at the expense of increased conductor rail insulation problems. It will be recalled that in Chapter Two it was explained that locomotive traction motors require a high current at starting with a low voltage and a lower current and high voltage at speed. As railways to run at over 200 mile/h will be highly specialised it is considered probable that the circuitry to achieve the differing relationship between current and voltage will be removed from the locomotive and placed in the relevant electricity sub-station. The locomotive will thus pick up power exactly suited to its needs and except for stretches where maximum speed will be needed the conductor rails will not be required to carry maximum voltage. In these circumstances power supply would become part of the command and control system, this term being used as there would be no driver and no lineside signals—so that command and control can no longer be called signalling.

Signalling techniques for high speeds, or command and control techniques, have already been outlined in Chapters Four and Five. Automation will be essential, the degree of automation increasing with the speed. European railways using intermittent cab signalling have decided that continuous cab signalling will be essential above 125 mile/h and some administrations put it at 100 mile/h. At some speed yet to be decided the driving of the train will be taken right out of the driver's hands and he will be eliminated as no longer performing a useful function. A little while ago in Great Britain a film was shown to the Institution of Signal Engineers that was taken from the cab of an electric locomotive travelling at 100 mile/h and showed the driver's view of the lineside signals. The film was run through a second time at a simulated speed of 125 mile/h and then again at 155 mile/h. Although the audience had just seen the film twice before, many of its members noticed that at 155 mile/h they missed many of the lineside signals. At that speed too, cab signals can change with such rapidity that an unreasonable pitch of concentration is demanded of the driver, it is essential that he is backed up by a braking programmer or data processing equipment so that out of course signal stops are made for him automatically. While he will be competent to make booked stops, here again automation is advisable, for it is likely that caution will bring about delays because braking is commenced too soon. As in any case he will not be able to reduce the speed of the train appreciably should he see an obstruction on the line ahead when travelling at above 100 mile/h, the driver's use is at an end and logically he can be eliminated.

Some railway systems are worried about high speed trains passing each other at a combined speed of say 300 mile/h on adjacent tracks, the air shock forces might be high enough to cause damage. The Italian State Railways for one is moving tracks apart for this reason. At present the overall allowable width for coaches and spacing of tracks gives one foot between passing trains (less than in Great Britain), in future it is to be 2 ft 7 $\frac{1}{4}$ in. Both British Rail and the German Federal Railway have conducted tests to see if passing train

HIGH SPEED RAILWAYS

air shocks are within acceptable limits on their systems for high speeds. The violence of air movements in tunnels has also been studied. The Channel Tunnel as designed will have three bores, one tunnel for the trains in each direction and a tunnel for services between them. All three tunnels will be frequently interconnected and the air movements brought about by moving trains have been designed for their unimpeded progress up to 100 mile/h. Tunnel entrances also will be a source of difficulty for trains entering at high speed, even with a double-track tunnel, will have to in effect suddenly bring a column of air stretching nearly the length of the tunnel up to something approaching their own speed. On the Florence-Rome 155 mile/h line now under construction compression chambers are being built outside each tunnel mouth to allow a gradual build-up of air pressure. These take the form of reinforced concrete shells which continue the tunnel bore shape for 55 yd outside the mouth. Slots to the open air that will extend from near rail level almost to the peak of the roof will be cut in the shell sides. The first slot will be 13 ft 9 in wide and allow for a maximum escape of air in front of a moving train, then the slots will diminish in width until the last before the tunnel mouth will be only 4 in wide. The problem has been encountered before, even at low speeds. London Transport 'tube' trains fit their tunnels very closely and at points where these trains are likely to enter a tunnel from the open air at speed the tunnel mouths are bell-shaped to provide for gradual build-up of pressure.

Other precautions necessary for high speed include the elimination of all rail crossings, that is one pair of rails crossing another at an angle. Points necessarily involve a single rail crossing another rail and here 'moveable frogs' are proposed. That is, as well as the point blades being moved, the angle where the two converging rails meet at the crossing will also be moved, to mate with the particular running rail in use. By this means the wheels will be presented with a continuous surface at all times. These measures are to decrease maintenance, which will in any case present problems as high speed railways are likely to be heavily used in order to get a return on the capital expended. On the Florence-Rome high-speed line the existence of the old railway now being used will allow whole sections to be shut for maintenance, but in addition crossovers are being installed every ten miles or so. These will allow trains in both directions to use a single track while the other is being maintained, although the crossovers will have a speed limit of 60 mile/h which will bring about delays. British Rail has already installed maintenance crossovers of this sort on some of its main lines. A remarkable provision on the Italian line will be the hollowing out of great caverns in the sides of some of the longer tunnels in order to store track maintenance machinery. For really high speed lines equipped with high voltage conductor rails there will be nothing for it but to close the railway for a few hours from time to time for maintenance, or at least for inspection for no doubt they will be built to be maintenance-free as far as possible.

It almost goes without saying that on any railway to be used at speeds above 100 mile/h there will be no level crossings—more capital expense will be

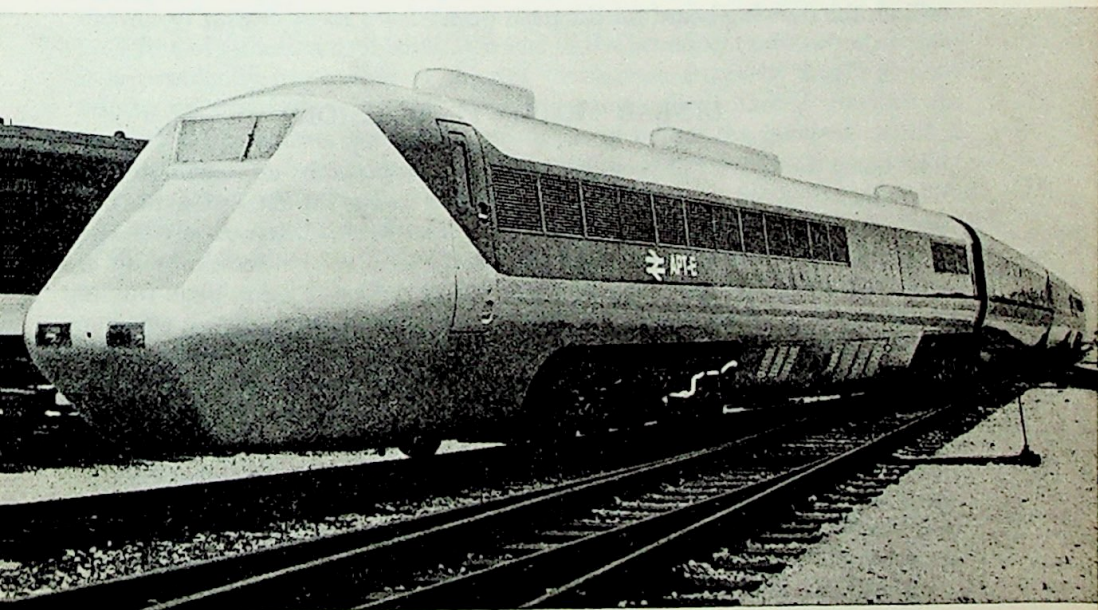
involved in providing under and over bridges. The line will have to be well-fenced too, for even the smallest obstruction may have the most disastrous consequences. The Florence-Rome line as far as possible will have walls, inserted into the sides of embankments and in the slopes of cuttings, the latter reinforced by fencing. The Japanese 310 mile/h magnetic levitation line will be enclosed throughout its length in a translucent plastics tunnel, or so it is proposed. This is to protect the trains from the effects of rain or snow and it may well be that a similar covering will be considered for very high speed orthodox railways. Finally of course high speed railways must be as straight as possible, which leads to a great deal of tunnelling work and viaducts. They need not be level necessarily, within reason, although the rate of change of gradient must be watched. British Rail calculated a few years ago that should it run one of its existing class 86 electric locomotives at 200 mile/h over the summits at Tring and Roade on the Euston-Rugby section, the then change of gradient was so abrupt that the locomotive would leave the rails and fly into the air. It would only rise momentarily for not more than three-quarters of an inch, but there was no guarantee that the wheels would hit the rails again in the right position.

The trains to run at high speed will have to be modified for the duty, not only to suit them to the purpose but also to ensure minimum maintenance. British Rail has put ten years or more of research into its Advanced Passenger Train, which is now running trials. In its way it is a compromise, for it must operate satisfactorily over existing railways, but nevertheless the train is designed with the highest speeds in mind. Present-day main lines are signalled for 100 mile/h, but thanks to the hydrodynamic brake, described in Chapter Three, the braking performance of the train will be such that it will be possible to operate it up to 125 mile/h with the existing lineside signalling and intermittent cab signalling, or up to 155 mile/h with the same signals and continuous cab signalling. The Advanced Passenger Train will be air-conditioned, not so much for the comfort of the passengers but because above 100 mile/h windows cannot be opened. The resultant air currents would be far too strong and the attainment of the train's maximum speed might be prevented because of the increased air resistance. The train has streamlined noses front and rear (it runs with equal facility in each direction) and the length of the train is air-smoothed. The coaches are of semi-monocoque construction, based on the principles learnt when engineers designed frames for aircraft. Railways have been criticised for slowness in adopting airframe design techniques, but they had a practical objection to their use. The old Northern Railway of France built a considerable number of coaches with steel semi-monocoque bodies in the 1930s. In due course some of these were involved in railway accidents. In a coach of orthodox construction the end receiving the impact collapses and that is where the killed and injured are, the rest of the passengers escape comparatively lightly. In semi-monocoque coaches it was observed that the frame was so strong that the killed and injured were distributed the length of the coach and that there tended to be more of them. The same phenomenon can be noted when an aircraft crashes.

The Advanced Passenger Train hopefully has a collapsible front and rear nose to get over the difficulty.

The major innovation in the Advanced Passenger Train concerns the suspension and wheels. Rails have tops that slope inwards towards the centre of the track at 1 in 20 and the wheel tyres (comprising a flange and a tread) have treads at a similar inclination. The tread traditionally is joined to the flange by what is known as a coned curve. The theory behind it is that should a wheel flange be thrust hard up against a rail the wheel will ride up on the coned curve. The effect is to enlarge the wheel diameter and it will want to revolve faster for a given speed. The wheel fixed to the other end of the axle will be running on its outer tread and revolving more slowly, the drag on the wheel wishing to run faster pulling the latter off its coned curve into the desired central position on the track with both wheels running on their treads. The trouble is that the tyres wear unevenly and when wheels are turned in a lathe to restore the coned curve shape a great deal of metal has to be taken off the treads and wasted. Professor Dr. Heumann in Germany commenced advocating a more reasonable tyre profile in the 1930s, moulded to the rail shape so that wear took place as evenly as possible on both tread and flange. Building on Professor Dr. Heumann's work, British Rail laboratories have worked out a suspension design that will avoid bringing the flanges into contact with the rails at all, creep forces between the tread and the rail will suffice to keep the wheelset in the centre of the track. The flanges will remain, but only as a safety back-up feature.

Power car of British Rail gas turbine-electric articulated four-coach prototype Advanced Passenger Train



To maintain this method of guidance when rounding curves as well as along straight track the axles of the train must continue to lie at right-angles to the track at any given point. That is the axles must at all times be parallel with the curve radius. To permit this the suspension is designed to allow angular movement of the axles in relation to the bogie frames. The reason for this angular movement is new but the idea is not, Ing Klose of the Württemberg State Railways designed locomotives with just such an angular movement of the axles about 1880 and a considerable number were built. Ing Klose wished to prevent excessive grinding of the flanges along the rails at the outer ends of long-wheelbase locomotives when rounding curves, while in the Advanced Passenger Train it is wished to prevent any contact between flange and rail. The suspension has other features directed towards the same end as well as the provision of angular movement for the axles. Because the track is relieved of intermittent sideways blows from the flanges of passing trains, maintenance will be decreased and to assist this aim of less maintenance the axleloading will not exceed 16 tons, a drop of some 20 per cent compared with previous British Rail practice. Few other railways have gone to the trouble that British Rail has to design a high speed train as yet. The French test gas turbine-driven trains TGV.001 and RTG.01, now running trials, are designed for 185 mile/h. In the United States the ill-starred Metroliner trains running between New York and Washington were supposedly designed for 160 mile/h but for one reason and another are now limited to 100 mile/h. One of the trains of the New Tokaido line has reached 177 mile/h on trial, but it was concluded that the design was not really suitable for this speed. The prototype Italian tilting-coach train now running trials is designed for 155 mile/h. Elsewhere locomotives and trains for more than 125 mile/h are still on the drawing board for the most part.

LINEAR MOTOR PROPULSION

The linear motor for rail propulsion was first proposed by a German in 1905. The idea remained on paper, which was just as well as the details had not been worked out in a manner that ensured success. In the linear motor electro-magnets corresponding to those in the stator of a rotary electric motor are mounted on the vehicle to be driven and they repel a reaction plate running along the track, thus driving the vehicle forward. For the highest efficiency there must be a considerable speed difference between the magnets and the reaction plate, not reached until the vehicle is travelling at above, say, 200 mile/h. Electrically the best material for the reaction plate is copper, but for a plate standing two feet or so high this metal is too expensive for railway use and in any case would be a temptation to thieves. Steel does not give such a good electrical performance and so aluminium is the favoured metal. The vehicle electro-magnets are arranged on each side of the vertical reaction plate and as near as they can be to it. Here lies a difficulty for the magnets should be as close to the reaction plate as possible for maximum

efficiency, but this is not allowable because of the sideways movements of the vehicle. Space has to be allowed for this sideways movement, in practice about one inch on each side of the plate, which leads to a considerable performance reduction. More power has to be applied than is really necessary to drive the vehicle. More recently it has been proposed to lay the reaction plate flat along the sleepers (raised above them by the height of the rails at least) and to hang the electro-magnets down from the vehicle facing the plate. This arrangement exchanges the sideways movements for the vertical movements of the springs, unless it is proposed that the magnets are an unsprung weight to be carried direct on the rails.

The most important advantage of the linear motor for rail traction is that all adhesion problems are avoided. Adhesion, the ability of the steel wheel to push hard enough at the steel rail to drive the train along, has worried engineers since the earliest days. An ingenious Mr. Blenkinsop concluded erroneously in 1812 that adhesion was insufficient and fitted a locomotive for colliery service in Leeds with rack-and-pinion propulsion. Nowadays it is noted that adhesion becomes less as train speeds increase and there is serious doubt as to whether or not there would be sufficient to drive trains travelling at much above 200 mile/h. It will be a matter for a practical experiment that so far no railway administration has found it profitable to make. It is true that the French National Railways ran an electric locomotive up to 205.6 mile/h in 1955, a railway world record, but what is required is a much more prolonged trial in all sorts of weather to see if rather higher speeds than that can be regularly attained. The linear motor does away with all these doubts, the wheels merely carry the train and traction adhesion does not come into it. Furthermore if the motor is put into reverse, that is the magnets attract instead of repelling, an exceedingly powerful brake is available that is similarly free of adhesion problems. It is one of the beneficent gifts of nature that it is practically impossible to damage the human frame by braking when relying on adhesion, other than throwing people about hard if they are not warned as to what is going to happen. Long before the blackout point is reached the wheels pick up and start to slide along the rails. It is otherwise with the linear motor brake which will give much greater rates of deceleration and safety cut-outs will have to be applied.

British Rail did a great deal of work on the linear motor during the 1960s (more than any other transport concern so far) up to and including small test vehicles. They reached the conclusion that it would be uneconomic compared with present traction methods at speeds below 200 mile/h, and possibly at speeds some way above that if adhesion problems were favourably solved. Its major objections concerned the inefficient use of power, the cost of the reaction plate and the difficulties likely to be encountered at points and crossings. There were other objections at the time as it was thinking in terms of a vertical reaction plate, objections that might now be overcome by the use of a flat reaction plate. These latter objections included the difficulty of fitting the reaction plate into the loading gauge, for it would have to go outside the side of the train as there was no room underneath, and trouble on

curves because of the length of the electro-magnets and their closeness to the reaction plate. The development of continuous slab solid-bed track may overcome yet another objection, that the reaction plate would make the use of track maintenance machinery impossible. The first three major objections are the crucial ones and will probably ensure that the linear motor is not used on any railway carrying a variety of traffic, even should this traffic need to be carried at over 200 mile/h. The linear motor will be reserved for specialised railways only with a minimum of points and crossings and great regularity of traffic.

As this book is being written news has come in that British Rail has proposed a 250 mile/h linear-motored railway between the London railway stations of Kings Cross and Euston and the new Foulness Airport to the east of London, the first serious proposal for an orthodox railway to reach this speed. The line will be about fifty-three miles long and the trains will cover the distance in 20 minutes, to convey aircraft passengers to and from the airport. The railway will be complete in itself and for passengers only; no connection with any other line is contemplated, except perhaps for service reasons. Nevertheless it will be standard gauge as this gauge has shown itself to be entirely satisfactory for high speed operations and in any case it will be convenient to haul rolling stock for overhaul to and from works over the rest of British Rail. The first ten miles or so through London will be in tunnel and then the railway will run in a straight line for the airport. It is expected that the track will be laid on continuous reinforced concrete solid-bed slab throughout. British Rail's Advanced Passenger Train will supply the rolling stock, the necessary electro-magnets being supported by a trolley running directly on the rails. The trolley will be held rigidly fore and aft to transmit the traction and braking forces but will be free to move sideways to accommodate itself to the rails. It is probable that three-phase power will be supplied through third, fourth and fifth rails. The trains will have no driver and command and control will be possibly integrated with the power supply as it may be that sub-stations will provide each train with the voltage and frequency necessary for the speed desired at any given moment.

The use of the Advanced Passenger Train with a linear motor on the above railway is a change in British Rail plans, for previously it had had hopes that the improved adhesion offered by the better suspension and the improved tyre profile would allow it to run a train up to 250 mile/h with orthodox electric motors. It may be hazarded that politics, both railway and national, have played a part in this choice of the linear motor for propulsion. The British Rail proposal is in competition with an alternative hovertrain link with the airport and to impress those who will have to choose between the two projects it may have considered it better to put all the latest technological toys in the shop window. The government in its turn, having built a new airport, wishes to impress the world with the latest in British engineering by the means by which travellers are hastened towards town. It may be observed that governments in general have yet to tumble to the fact that today engineering is highly international, or in any event the people that they

represent do not realise this. Thus British Rail's Advanced Passenger Train will probably feature Swedish equipment and the French high speed RTG.01 has German hydraulic transmissions. As an extreme case all Russian electric locomotive-hauled high speed express trains use German-, Czech- or French-built motive power, and these locomotives in turn incorporate components from half-a-dozen other countries. British thyristors and toughened glass are incorporated in Italian motive power, Italian machines are used to spray-paint British coaches rail blue and so on, the list is endless.

In this chapter the efforts that the railways are making to give a faster service have been reviewed. There is an economic case for high speed and the various administrations are reacting accordingly. The first aim is a widespread attainment of 125 mile/h, to be followed soon after by 155 mile/h. Beyond that up to 200 mile/h or beyond for the orthodox railway is in the yet unplanned future, but a future that is being given a good deal of thought. Speed may leap-frog over the orthodox railway to the highly specialised line of the sort that is being planned by British Rail for 250 mile/h between London and Foulness. It is worth noting that railways cannot go on pushing up their maximum speed indefinitely, nor indeed can almost any other form of land transport. The reason is air resistance; at about 300-350 mile/h this resistance becomes so high and the horsepower to overcome it becomes so enormous that the undertaking is quite uneconomic, whatever the fares or rates charged. It is air resistance that sends an aircraft up into the rarefied atmosphere above 10,000 feet, even for such a short hop as that between London and Paris. Air resistance is so much less at that height and above that the horsepower required drops greatly and there is a considerable fuel saving.

CHAPTER SEVEN

Other guided transport modes

MONORAILS

The book so far has concentrated on one particular guided transport mode using steel rails for guidance. This orthodox type of railway is of course in use all over the world and thus justifies the space given to it. In guided transport jargon it is being referred to as the duorail mode, a useful term now to be employed. Despite its universal use the duorail mode has had a rival for over one hundred years, the monorail. In the 1860s the idea was to lay a single guide rail on the ground for support and drive the train by wheels running on a road alongside. In the 1880s Mon Lartigue proposed a monorail supported by a continuous triangular trestle, the rail proper being at the apex of the triangle about four feet above the ground with lesser guide rails running on each side of the trestle lower down. Both locomotives (with two boilers) and rolling stock were made in two parts slung over the trestle. Lartigue monorails saw brief service in France and in Algeria and a line ran for 36 years between Listowel and Ballybunion in Ireland. Lartigue's idea was improved and demonstrated as a high speed line by Mon Behr in Belgium and in 1901 an Act of Parliament was obtained for a Behr railway between Liverpool and Manchester. It was to be worked by fast electric cars for passenger use, but nothing came of the scheme. In 1910 Louis Brennan demonstrated a true monorail at an exhibition in London. His cars balanced on a single rail with the aid of a gyroscope and high speed was claimed, but nothing came of this demonstration either.

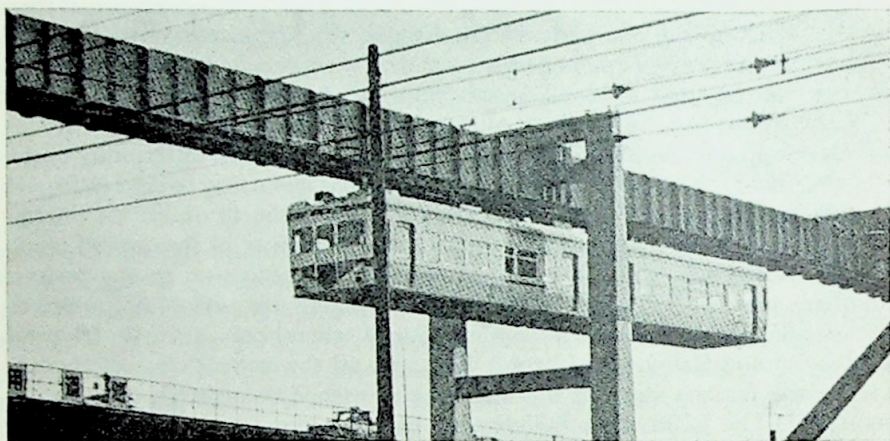
In 1920 the Bennie railplane was demonstrated on a track at Milngavie in Glasgow. Bennie's cars hung from a rail 30 feet or more in the air with a light guide rail underneath and they were driven by an aeroplane propeller. A cruising speed of 160 mile/h was claimed with a maximum speed of 200 mile/h and it was suggested that the 400 miles between London and Glasgow could be covered in three hours. Most of the test track was soon taken down, all except for the station which mouldered away for 20 years until it was cleared for scrap metal in the second world war, complete with the passenger car which had been hanging at the platform. The company lasted longer,

it still had a brass plate up in Victoria Street, London, in the early 1950s. Moving onwards we come to the Alweg monorail of the 1950s, with a car that rode on rubber tyres on top of a reinforced concrete beam with side guidance also taken from the beam. High speeds were claimed. Exhibition lines were built at Turin and at Seattle in the United States and in 1964 the Hitachi-Alweg monorail route opened between Tokyo and a new airport. No very high speeds are attained on this line, although it works well enough. Alweg publicity was good and a number of architects and town planners were moved to include monorails in the new towns and re-arranged city schemes that they had in hand during the early 1960s. After a while transport men took the architects and town planners gently by the hand and explained the facts of life to them and another fashionable fad disappeared.

What are the facts of life about monorails? And why have 100 years of monorail development resulted in so little? The answer lies in the inflexibility of the system. Just as the duorail country branch line has given way to road transport because of the latter's superior flexibility, so has the flexibility of duorail proved superior to monorail. Recognising this flexibility of the duorail mode nearly all the schemes for monorails have been specialised in one way or another, usually for passenger transport. Among the monorail proposals mentioned (and there were a large number of others) only the little Listowel & Ballybunion Railway endeavoured to carry all the traffic that was offering. Hence the famous story of the farmer who wished to dispatch one cow by monorail. The Listowel & Ballybunion had to borrow a couple of calves to balance the cow in its van on one side of the trestle, subsequently separating the calves to ride on each side of the trestle for the journey back to their owner. In effect this Lartigue monorail ran on a fence four feet high across the countryside and it had trouble at level crossings. The approach roads had to be embanked up to the level of the top of the trestle and a sort of lifting bridge put in between the road abutments, the leaves of which came down to rest on the top of the trestle to provide the road surface. Perhaps it is unfair to epitomise monorail troubles in terms of a line over eighty years old, but each monorail system meets its own sort of trouble on these lines. A great stumbling block are points and crossings. No system has yet devised points that are other than slow-acting and expensive and in addition call for a severe speed restriction, while crossings are near impossible. When duorail trains are crowded with passengers it is a simple matter to add an extra coach or two, or to run an extra train after the first. With monorails such accommodation for the level of traffic is difficult and costly. Thus monorail routes not only have to be designed for a specific traffic but they also have to be designed for a specific level of that traffic—in short they are inflexible. Space has been devoted here to reciting the difficulties of monorails because later in this chapter hovertrains and magnetic levitation trains will be described and both these systems have precisely the same inflexibility as a monorail—their only advantage is speed and more speed.

A monorail yet to be mentioned has been running at Barmen in the Wuppertal in Germany for sixty years or so and it is an excellent example of a

specialised need being met. Wuppertal is a very narrow ravine and the streets alongside the river are too narrow for a tram service. So an elevated monorail track was built above the river itself from which the electric cars hang. The line can expect many years of life yet for a few years ago some renewing of the supports was carried out and a complete set of new cars has been provided. Monorail systems are still being developed, the Safege system for example was devised in France in the 1960s and had its first application on a Japanese



The Yokosuki Safege monorail in operation in Japan

suburban branch line in 1971. This is another suspended system and perhaps the purist would not allow it to be called a monorail at all, for the cars hang from a four-wheel bogie which has horizontal guide wheels in addition. This bogie runs inside a cavity in a reinforced concrete beam (or alternatively inside steel girders), a slot between the wheels allowing for the arm that supports the car. The wheels of the bogie are rubber-tyred and run on timber planks inside the concrete cavity, while the guide wheels which run against the cavity walls are similarly rubber-tyred. The French have a bee in their bonnets about rubber tyres; several RATP duorail lines of the Paris Métro have guide rails and rubber-tyred rolling stock in addition to steel rails and French-inspired rapid transit lines at Montreal and Mexico City are similarly equipped. Adhesion is improved but on the other hand so is rolling resistance, so that more power is required to drive the train. On underground lines it is difficult to disperse the heat generated by the traction motors and developed in braking and the atmosphere becomes very warm, on the other hand the noise level is cut.

Another suspended monorail system has been developed recently by the Rohr Corporation in the United States and being new it has yet to find an application. In this case the intention is to cater for very low passenger traffic flows and hence the cars have accommodation for six people only and

the construction is very light for minimum capital cost. In Japan a rapid transit line opened at Sapporo, the capital of the northern island of Hokkaido, in 1970 that reverts in part to the monorail idea of the 1860s, the car runs on rubber-tyred wheels and further horizontal rubber-tyred wheels bear against a central steel rail for guidance. Northerly as it is, Sapporo has a very heavy snowfall in winter and the surface stretches of this line have been protected throughout their length by a steel and light alloy tunnel with suitable windows. All these post-second world war monorails are electrically driven and again there are other systems that have not been mentioned. The monorail idea is ever-present in the minds of inventors and developers and they are always trying to solve the various problems.

HOVERTRAINS

The post-second world war development of the hovercraft lifted off the ground by air pads has a high speed potential, always providing that it has a level surface to run over and some sort of guidance system to keep it on it. Thus the appearance of the hovertrain. No hovertrain lines have yet been built and the various systems that have been devised are still in the experiment and test stage. The French were first in the field with a test vehicle and a short length of track for it in 1966; 262 mile/h has been attained with the aid of rocket propulsion. A much more ambitious test track was opened near Orleans in 1969. This is 11 miles long and an 80-seat vehicle has reached 185 mile/h on it. In this latter French system the track takes the form of a reinforced concrete inverted T-beam. The vehicle straddles the upright leg of the T and air pads support it on the horizontal surface. Additional air pads bearing against the upright leg control sideways movements. Gas turbines provide the necessary power and drive the vehicle forward by means of an airscrew. The airscrew is all right for a test vehicle but it is recognised that it is far too noisy for public use and it is proposed to use a linear motor for a commercial line authorised over the 16 miles between La Défense and Cergy near Paris.

Next, a hovertrain test track was opened for three miles in Great Britain in 1971 with a site potential for an extension to 20 miles if required. The British track is a 4 ft 6 in wide reinforced concrete beam 6 ft 4 in high, which it is intended to carry high above the ground on supports. These standard track beams will be cast in 75-ft lengths and it is proposed to make curves by a series of the beams set at a slight angle to each other. This will be possible as both vertical and horizontal curves will have to be of an exceedingly large radius to deal with the intended maximum speeds of up to 310 mile/h. Cars will straddle the beam and will be supported by air pads bearing on the top supplemented by guidance air pads bearing on the sides. These side pads are of considerable importance, they will have to take up the different beam angles when rounding curves for example and deal with the effect of side winds. Traction and braking will be given by a linear motor with a horizontal

steel reaction plate let into the top of the concrete beam and covered by an aluminium plate to prevent corrosion and improve conductivity. Conductor rails underneath the concrete beam will supply three-phase traction current and its voltage and frequency will be adjusted to the needs of the vehicle

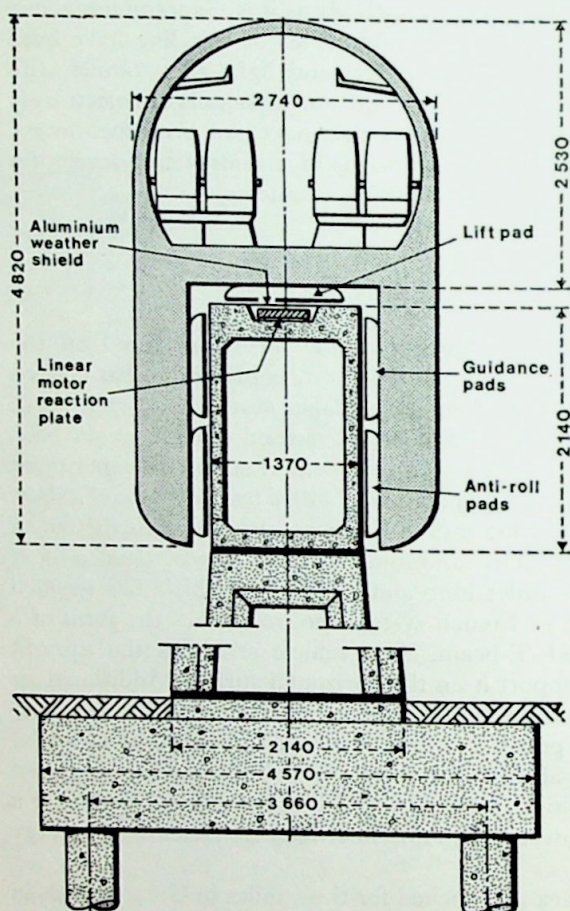


Figure 2 : Cross-section of proposed British hovertrain vehicle and track. Dimensions in millimetres

at the line's sub-stations. One reason for this is that the weight of the necessary control circuitry if put on board would add up to such a figure that the payload would be cut considerably. Control and command of the unmanned (or at any rate driverless) vehicle will be by an induction automatic train operation system as described in Chapter Six and the British test vehicle is already being operated in this manner. Control and command will be simplified as far as interlocking is concerned for there will be few if any points.

For the moment the British test vehicle is being used to solve the problems of getting a hovertrain to go satisfactorily. These problems are formidable enough and include the difficulty of getting an efficient drive by linear motor for a vehicle whose electro-magnets move up and down on springs in relation

to the reaction plate. The gap between the magnets and the reaction plate must be as small as possible at all times, as must the gap between the air pads and the beam. The difference between a $\frac{1}{4}$ in gap and a $\frac{1}{2}$ in gap for these latter can add greatly to the horsepower required for operation. The solutions being tried are electro-hydraulic servo-motors with suitable command circuitry to maintain the air gaps constant. This apparatus will have to be fast and accurate, for not only will it have to deal with the spring movements of the vehicle but also with variations in the motor magnetic forces, side wind forces and differences in beam angles, all at speeds up to 310 mile/h. Collection of current too will have its difficulties, including maintenance of constant contact with the conductor rails at high speed from a vehicle bouncing on springs, coupled with the need for a stiff arm from the vehicle to keep the collecting shoes in position in relation to the conductors, or, alternatively, possibly some guidance of the shoes at conductor rail level. Collection is from the top of the conductor rails on the trial track, just as on British Rail's 750 V d.c. lines. The latter's conductor rails ice up two or three days each year and trains have difficulty in moving, which will happen to hovertrains too unless some other method of collecting current from the rails is worked out.

Even when the test vehicle has been made to go satisfactorily there will be problems. In order to maintain passenger comfort a horizontal curve radius of just over $2\frac{3}{4}$ miles must be accepted for superelevated curves and a speed of 250 mile/h. Superelevation cannot be very great because vehicles may traverse the curve slowly or even stop on it. A curve radius of two miles is possible with a speed limitation of 200 mile/h but on the other hand if it is wished to run at 310 mile/h the minimum curve radius acceptable goes up to six miles. Vertical curves, those acceptable when going over a hump, must have a minimum radius of eight miles at 250 mile/h. These limits apply equally to the duorail and monorail modes of course, and, just as on duorail, sharper curves can be used provided the complication of a tilting body is applied to soften the effects of curving for the passengers. For commercial reasons speed must be maintained by hovertrains and the provision of a sufficiently straight track will bring about difficulties in planning a line. There will be no possibility of going round such minor obstacles as villages, small towns or industrial and other estates, it will be a matter of straight ahead regardless. Fortunately, unlike duorail, the curve problem is mitigated slightly by a greater tolerance of gradients by the hovertrain. It is anticipated that a single car climbing a 1 in 50 gradient at 250 mile/h would only require a 10 per cent increase in power compared to that necessary for running on the level. This low figure looks good, but it is really the result of the enormous amount of power required to drive a hovertrain at high speed, most of which is devoted to overcoming air resistance.

Tunnels are another problem and indeed the Japanese have lost interest in hovertrains because of the great amount of tunnelling that would be necessary in their mountainous terrain. The hovertrain requires to suck in such an enormous amount of air for its air pads as it runs along that it is considered that unpredictable and dangerous air currents are likely to arise in the confines

of a tunnel. It would be unfortunate indeed if the passengers suddenly found themselves in a vacuum. The ability to climb steep gradients cuts down the need for tunnels of course, but this in turn will probably call for considerable earthworks and very high viaducts as attempts are made to meet the eight-mile minimum vertical curve radius necessary for the maintenance of high speed. An operating problem concerns braking, for the linear motor braking mode is not fail safe. Should the current to the electro-magnets fail while at speed the vehicle would be left without any means of stopping. Should all electric current fail while at speed the air pads would lose their power and the vehicle would flop down on its track, this has led to the suggestion that the provision of skids to bear on the top and sides of the concrete beam would bring the vehicle to halt in an emergency. Skids are perhaps a little drastic and maybe air-braked wheels will be the answer. Finally, points to move vehicles from one track to another. Here the developers are left scratching their heads, the best they can think up is some sort of flexible beam which can be pointed in one direction or another. Construction would be expensive but worst of all it is probable that a speed limit of about 10 mile/h would be necessary, which is not so good when a maximum speed of 310 mile/h is the aim. It is easy of course to list all the difficulties of a new transport mode like this and no doubt they will be all anticipated and overcome—at a price. The price is important for in order to be competitive with other transport modes the promoters are relying on lower capital costs, so these must be held down.

On the assumption that hovertrains will be able to operate successfully a large number of studies have been made of their likely commercial success on a great many routes, both in Great Britain and abroad. These studies are strictly commercial in the sense that if the shorter journey times offered by hovertrain compared with other transport modes can be given at a comparable fare it is taken that the operation will be successful. So it will be no doubt, but if the competing mode is duorail the commercial approach fails to take into account the more flexible nature of that transport mode. Supposing a successful passenger hovertrain operation between London and Manchester, the passenger traffic removed from duorail is only part of the load. The London-Manchester duorail route carries passengers and freight to other distant destinations, as well as for intermediate stations. The passenger traffic removed might represent the whole profit and more of the duorail operation, so a successful hovertrain route could have the result for duorail of losses on other traffic not catered for by the hovertrain. It is suggested that a wider viewpoint than mere commercial success must be taken to ascertain the true national interest. A London-Manchester hovertrain route fundamentally will save passenger's time and this time saving can be costed. By costing the saving the total sum saved over the year can be related to the capital necessary to establish the hovertrain route and the likely operating expenses.

Taking the London-Manchester travellers to be business men and assuming an average annual salary of £4,000 per year, a ten-hour working day and 200 working days a year, the traveller's time can be costed at £2 per hour. Assum-

ing that the hovertrain does the journey in one hour (average speed 185 mile/h) and duorail in two hours (average speed $97\frac{1}{2}$ mile/h by Advanced Passenger Train), each passenger carried will gain an average saving of £2. Taking a passenger flow of $2\frac{1}{2}$ million each way each year (6,850 passengers each way for every day in the year) the total national saving will be £10 million. This would be about the sum necessary to service a £113 million construction cost. It is stated by the authorities that a fully-equipped hovertrain route would cost about $\pounds\frac{3}{4}$ million per mile, which gives a cost for a 185-mile London-Manchester route of £113 million. The $\pounds\frac{3}{4}$ million per mile does not allow for land acquisition or wayleaves or the cost of rolling stock, nor is any allowance made for operating expenses. So on this rough calculation it can be shown that a hovertrain route is not worth building. It is true that the duorail Advanced Passenger Train will require some capital expenditure on modifying the route it is to follow, but on the other hand £4,000 per year is putting the average income per passenger pretty high and no allowance has been made for passengers travelling for pleasure who would not save anything like £2 per journey.

It is to be noted that traffic on a London-Manchester route could be increased by having an intermediate stop in the Birmingham area. Unfortunately this would not only increase the overall London-Manchester time by up to ten minutes but it would lead to operational difficulties, for trains would be apt to arrive full at Birmingham at the most popular times of day. Because of the difficulty in providing points, not to mention their capital expense, extra trains arriving and departing from Birmingham could not be readily provided. One can play about with loading and cost estimates for a long time in this way, but vary the factors how one will it is difficult to make out a convincing case for a hovertrain route in Great Britain so well served by high-speed duorail. Unless of course one pictures the future population as constantly on the move between the chief centres, coupled with an increase of bulk duorail freight loads. The Japanese are forecasting a massive increase in passenger traffic of this sort for their country, but no one has suggested anything of this kind as likely to happen in Great Britain.

There is a proposal afoot to connect London with the new airport to be built on Foulness Island by a hovertrain route to carry the aircraft passengers. The distance will be just over fifty miles, a distance so short that ordinarily it would not be considered worth while to provide a hovertrain line. The reason is that for distances of less than one hundred miles the time saving possible by hovertrain is minimal and thus the possibility of competing with established transport modes is greatly reduced. There are special circumstances on airport access routes that account for the discrepancy with this reasoning. Ordinarily, passenger traffic is subject to variations in flow during the day, such as peak traffic morning and evening going to and from work. There is also a considerable drop in traffic during the night. Aircraft passengers on the other hand travel almost all round the clock in a steady flow throughout, any tendency to peaks is limited by the capacity of the aircraft that can be got into and out of the airport. Airport access routes can be

designed therefore to a known passenger capacity and there is no need to install points and sidings and other facilities to marshal the extra vehicles required to meet peak periods. Capital costs can be reduced and they are reduced for hovertrain routes in particular because the cost of extra vehicles is high. Lower capital costs compensate for the lack of length in the line and there is the additional attraction that aircraft passengers can usually be charged a rather higher rate per mile than is normally possible. All these advantages apply equally to the rival duorail route described in Chapter Six of course. It is to be noted that both proposals envisage the carriage of aircraft passengers as the primary aim, although such people are usually in a minority among those who wish to travel to and from a great airport. As an example, 20 per cent of those wishing to go from the centre of Rome to the Leonardo da Vinci Airport are aircraft passengers, the balance are airport workers, visitors and so on. Carriage of this 80 per cent balance will produce high traffic peaks which is undesirable from the transport angle. From the strictly economic point of view for minimum transport costs it might be better to provide a rather slower duorail route to Foulness Island, the trains stopping at one or two intermediate stations for airport workers and running non-stop for aircraft passengers. Nevertheless, as mentioned in Chapter Six, there are prestige and publicity reasons for providing the fastest possible service for the aircraft passenger minority travelling to and from the airport.

Russia and the United States too are interested in hovertrains. The Department of Transportation for the United States has had a vehicle built that is supported on air pads on a flat reinforced concrete track equipped with reinforced concrete fences on each side, the air pads for sideways guidance working against the latter. This vehicle is about to be tested on a track building at the Department of Transportation's Pueblo test centre in Colorado. This Pueblo installation was started in 1970 and it is still being built. The major work will be a 21-mile oval of duorail equipped with a vertical linear motor reaction plate for speeds up to 250 mile/h, with a 21-mile oval of hovertrain track just inside it for speeds up to 310 mile/h. Smaller ovals will provide for testing present-day duorail motive power and rolling stock up to 120 mile/h and for rapid transit trains up to 80 mile/h. Provision will be made for testing other guided transport modes as required and the whole complex is supported by laboratories. This centre will be the more catholic counterpart of duorail test centres that already exist near Prague in Czechoslovakia and near Moscow in Russia. With the aid of the Pueblo centre a much more comprehensive evaluation of all the various guided transport modes that are now being evolved can be attempted and perhaps some costly errors will be avoided in future.

A United States estimate puts the capital costs of duorail, hovertrains and magnetic levitation trains for 250 mile/h routes all at much the same level. In Great Britain it is claimed that the capital cost of a hovertrain route would be rather less than that of a duorail route for comparable speeds. This may be so but the comment can be made that as the hovertrain runs on an elevated track the environmental blight caused will be rather greater than that likely from

duorail. The British claim of lower capital cost is based in part on the simplicity of the concrete beam track that is proposed. In contrast it is claimed that the French inverted-T track would be 75 per cent more costly and the United States trough track would cost twice as much. Other estimates made in Great Britain show that the power required to run a hovertrain at a constant 250 mile/h would be 9,500 hp, while a duorail car running at a similar speed would need 6,700 hp when powered by a linear motor (a power requirement that would drop to 5,300 hp if the rails could take the adhesion necessary for 250 mile/h) and a magnetic levitation car 4,700 hp. The high horsepower requirement of the hovertrain is a result of the great quantity of air that is required for the air pads to support the vehicle. This air has to be drawn in from outside the vehicle and, given that the outside air is stationary, the mass must be accelerated up to 250 mile/h before it can be used. At 250 mile/h nearly one-third of the power output is required for the purpose.

The range of utility for the hovertrain has been liberally estimated to be between 100 and 400 miles for passenger use, below the former mileage it was considered that the duorail mode would be competitive and above the latter aircraft would take the traffic. Now, as described in Chapter Six, duorail is proposing speeds that put it right into the hovertrain range of ability. Should the costs be much the same, and any lower capital cost for the hovertrain might be offset by higher operating costs, the hovertrain faces a poor outlook, especially as the magnetic levitation train is coming up fast to deliver the *coup de grâce*. Between duorail and magnetic levitation, hovertrains would appear to be obsolescent before they have even got off the ground, always excepting some specialised application, just as the monorail serves the Wuppertal while useless elsewhere.

MAGNETIC LEVITATION

The magnetic levitation guided transport mode is in a less developed state than the hovertrain. The Japanese were the first to have successful models and they are now engaged in building a full-size test track. The Germans have two different types of passenger-carrying test vehicles in existence and in the United States the various problems are under study prior to building the hardware. The Russians have started experiments as well. The principle is simple, magnets will either attract or repel one another according to whether unlike or like poles are presented to each other. It is immaterial which form of magnetic force is used, repulsion or attraction, and by suitably controlling the magnetic force a vehicle can be made to levitate or rise from the ground. Similarly, additional magnets can give control of sideways movements. Further control of the magnetic force can hold the vehicle at a constant height, whereupon it can be driven forward. For high speed the linear motor is the currently favoured mode of propulsion and up to 310 mile/h is contemplated.

The Japanese proposal for a magnetic levitation train will use magnetic repulsion to support the vehicle. The track will be composed of a continuous

series of powered electro-magnets. On board the vehicle superconductivity magnets will be mounted in which the track magnets will induce an opposing current, thus causing the vehicle to rise from the ground. Superconductivity is a state reached by some metals and in particular some of their alloys when cooled to nearly absolute zero temperature (minus 273°C). When superconductive these alloys have no resistance to the flow of an electric current

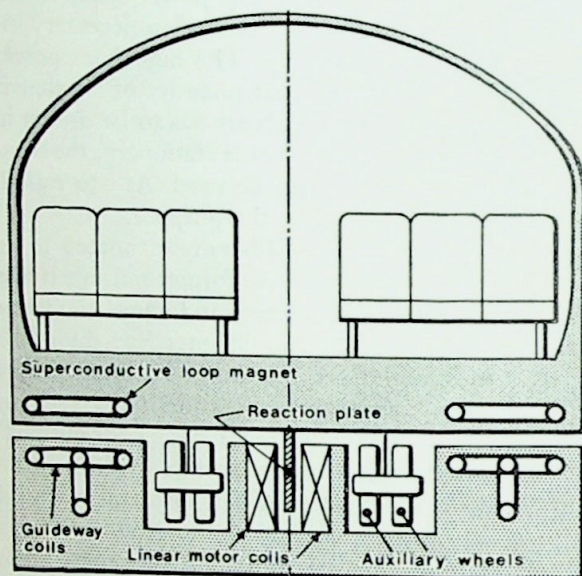


Figure 3: Cross-section of proposed Japanese magnetic levitation vehicle and track. The auxiliary wheels will support the vehicle when it is de-levitated

and indeed in theory an electric current once started in a superconductive circuit would go on flowing for ever. It is easy to induce a strong electric current from the ground in a superconductive electro-magnet mounted on a vehicle, the catch being that the magnet must be cooled to near absolute zero temperature on board in the first place.

The usual cooling medium for superconductive electro-magnets is liquid helium, the gas liquefying at minus 269°C or so. Helium is cooled by successive compression and expansion stages, the compression stages being so arranged that little heat is taken up by the gas. Apparatus must be arranged for this to be done on the vehicle, the process being started by conventional refrigeration, and for drawing off the eventual liquid helium. The electro-magnet windings will be closely sheathed with copper, on the outside surface of which the liquid helium will flow. The Japanese have discovered an alloy of vanadium and gallium which becomes superconductive at only minus 250°C and the use of this alloy for the wire of the electro-magnet windings will increase the cooling temperature gradient very satisfactorily. Superconductivity is not a stable phenomenon, for various reasons a superconductive magnet suddenly can become non-superconductive even when well below the critical temperature, with a danger that the windings will burn out unless they are protected. The reasons for this sudden change from the superconductive

state are now on the way to being understood and methods are being worked out to guard against them. Unfortunately, one reason for the loss of superconductivity can be a mechanical shock or jar of the electro-magnet and avoiding such jars on a vehicle rattling along at 310 mile/h will present problems. Another difficulty is that d.c. rather than a.c. is desirable for superconductive electro-magnets and the provision of ground d.c. electro-magnets will make it more expensive to supply current to them. On top of all this, superconductivity techniques have hardly emerged from the laboratory and there is little or no industrial experience upon which to base the desired apparatus.

The point of superconductivity magnets is that otherwise the magnets on board the vehicle would have to be so large and heavy that there would be little or no room for a payload. Furthermore, the magnets would have a voracious demand for electric current that would have to be picked up from a conductor rail or rails. The Japanese propose to avoid the use of conductor rails with their current pick-up problems altogether, by turning the linear motor round and placing the reaction plate on board the vehicle and having a continuous row of electro-magnets in the track. It is true that track support magnets will already be present on the ground, but nevertheless as it is proposed that the magnetic levitation line will be built between Tokyo and Osaka (to relieve the rapidly-growing passenger traffic of the New Tokaido railway) the provision of all these magnets over the 320 miles between the two cities will be an expensive item. A suggestion has been made that the vehicle should be treated as a projectile after it has been accelerated. A line of magnets would be provided for starting purposes to bring the vehicle up to a high speed, the last of these magnets giving the vehicle a kick that would send it skittering away down the track. Before the vehicle speed fell off too much it would encounter another magnet which would give it another kick and so on. What the passengers would make of this sort of progress perhaps has not been considered too closely as yet, but the economy in expensive track magnets is obvious. Power for cooling the superconductivity magnets and for the usual services for passenger light and heat will be provided by a diesel or gas turbine generator set on the vehicle. It is this magnetic levitation line, by-the-way, that it is proposed to protect from rain and snow throughout its length by a translucent plastics tunnel. No doubt it will be safer to keep snow and rain away from a vehicle travelling at 310 mile/h, but it sounds as if train travel on a line of this sort will be even duller than aircraft travel is now.

The German firm Krupp has done some work on a magnetic levitation vehicle with repelling magnets, but both Messerschmitt-Bölkow-Blohm and Krauss-Maffei have built vehicles that can carry a few passengers and that rely on magnetic attraction for support. The former runs astride an aluminium linear motor reaction rail with two steel angle guidance rails on each side of the vehicle. Magnets on the car pull it up to the underside of the angle for support and further magnets position it inside the angle uprights for sideways movements. Sensors continuously measure the distance between the magnets and the rails (about one inch) and the strength of the electro-magnetic current is

thyristor-controlled to ensure that the distance is kept constant. The reaction plate, steel angle rails and four conductor rails are all mounted on ordinary sleepers and ballast. The Krauss-Maffei vehicle runs on a reinforced concrete T-beam astride a centrally-placed linear motor reaction plate. On the underside of the arms of the T laminated iron channel rails are mounted, up to

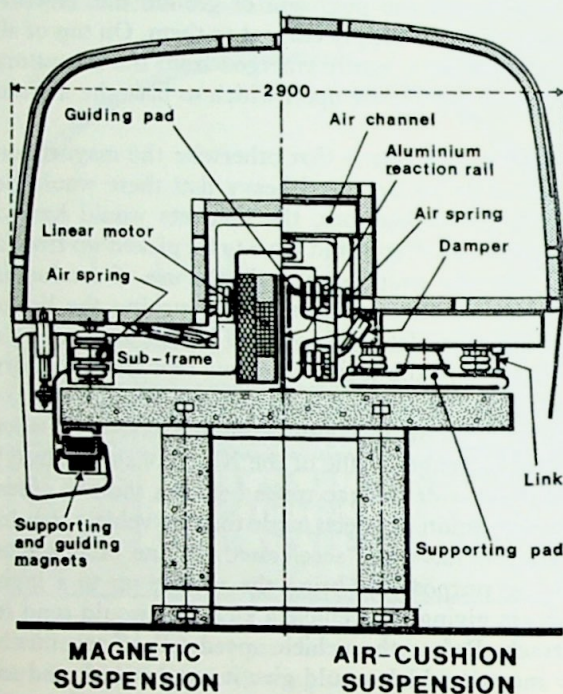
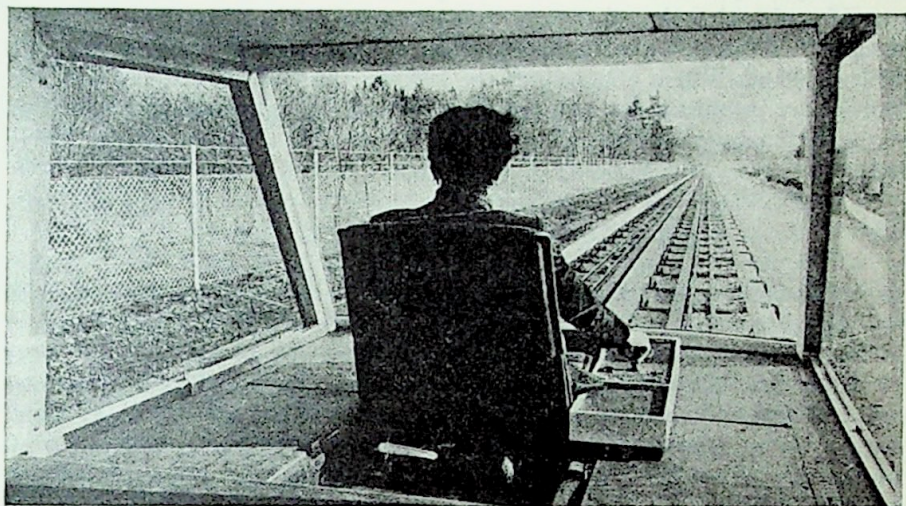


Figure 4: Cross-section of the Krauss-Maffei experimental magnetic levitation vehicle and track (left-hand) together with a proposed experimental hovertrain (right-hand). The conductor rails are not included in this drawing. Dimensions in millimetres

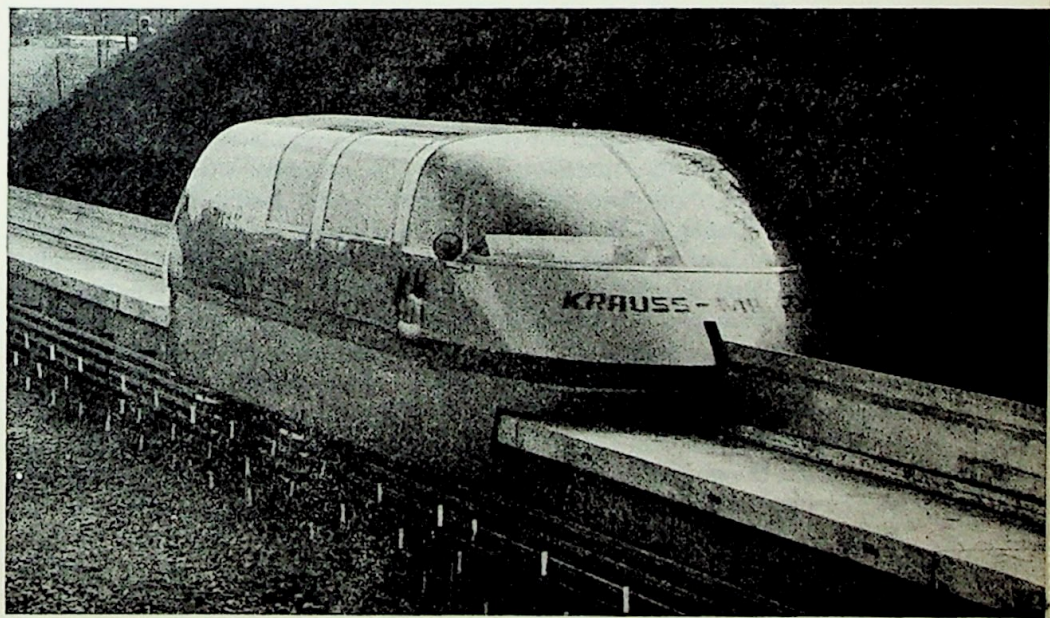
which the vehicle pulls itself by on-board magnets for support and guidance. Conductor rails are mounted on the leg of the T. In both of these systems the aluminium reaction plate has gaps at intervals to allow for expansion and contraction due to ambient temperature changes. The ultimate aim is to produce a 147-foot long vehicle that would be able to carry one standard 40-foot container or 144 passengers in a suitable saloon at speeds up to 310 mile/h. The installed power for the performance required would be 11,400 hp. A 40-mile track is to be built near Augsburg for full-scale tests.

All the magnetic levitation test vehicles so far built have been manually driven. Command and control of the vehicles by automatic means will present a considerable problem because of the exceedingly strong magnetic fields of the support and guidance system. These magnetic fields would swamp the normal induction links used for communication between the vehicle and the ground, unless perhaps a cable was slung above the vehicle's roof and even that is very doubtful. The strength of the magnetic fields too will call for some sort of protection for the passengers who ride in the trains, in the sense that the saloons will have to be shielded. Magnetic levitation is no



At the controls of Messerschmitt-Bölkow-Blohm's trial magnetic levitation vehicle

The Krauss-Maffei magnetic levitation test vehicle. The linear motor reaction plate may be seen and the traction current conductor rails are at the side of the track support



substitute for springing and the cars will have to be given both primary and secondary suspension. As a new transport mode magnetic levitation looks possible, provided that the economics are right, but the position was well summed up by an American engaged on a magnetic levitation project in the United States. When contrasting the system with hovertrains he said, 'It looks more promising because we haven't done enough research yet to find out what the bugs are'.

EVACUATED AND GRAVITY TUBES

As has been previously pointed out, high speed on the surface of the earth will be limited to about 350 mile/h because it will be uneconomic to overcome air resistance above that speed. In the United States proposals are now being made for a tunnel railway (duorail mode) in which the propulsion of vehicles will be done by evacuating the tunnel in front of them so that air pressure behind them pushes them along. As the air has been removed from in front of the vehicle air-resistance will be minimal and speeds of 500 mile/h are being talked about. The design of bogies and suspension for such vehicles will be critical. An evacuated-tube high-speed railway is proposed along the Washington-New York-Boston axis and the promoters have pointed out that with modern machinery the boring of a deep-level tube through the underlying granite and basalt would probably be cheaper than buying up land and wayleaves on the heavily-populated surface of the area. The Department of Transportation's Pueblo test centre has a 20-mile straight strip of land earmarked for an experimental evacuated tube should full-scale trials be required. The idea has been anticipated and London saw evacuated tube railways during the 1860s, or rather as there was only one steam engine for each line the tunnel was evacuated for trains in one direction and when they returned they were pushed by air pressure. A line was opened from Euston station to the head post office at St. Martins le Grand in 1865 and worked until 1874, the tunnel being built of bricks with a width of four feet and a depth of about four-and-a-half feet. Several people made a journey along the line lying down in the wagons at one time or another, as they did along 400 yards of test tube laid down in Battersea in 1861. One girl made a trip on the latter line, it being recorded that as she lay in the wagon head first her crinoline was blown by the air pressure right off her legs, which was considered an indelicate sight by those who waited at the end of the line to receive her. In the middle 1860s a full-size passenger-carrying line worked briefly for 600 yards in the grounds of the Crystal Palace, Sydenham, operations being assisted by a 1 in 15 or so gradient down on leaving and up on arrival. At the engine end iron doors closed the tunnel mouth automatically as the car entered and automatically opened for returning cars, the cars being blown outwards and sucked towards the engine on return.

There is a current proposal for a duorail gravity tube in the granite under New York's Manhattan. Trains on leaving a station would be accelerated by

gravity down a very steep gradient to reach perhaps 200 mile/h before meeting a steep up gradient to slow them for the next station. The trains would fit the tunnel tightly and would be given a puff of compressed air behind them to help them on their way, as well as possibly another in front to slow them on approaching the next station. As the force of gravity is universal and provided that the vertical section of the tunnel is at or near a segment of a circle, the beauty of the scheme is that no passenger would feel any acceleration or deceleration forces, despite the high speed. Furthermore, the need for power and complicated electronic gadgets on such a railway is small. Against the scheme is the fact that the stations would necessarily be at least three miles apart, which is too great a spacing for satisfactory rapid transit service. A gravity line paralleling an existing overloaded rapid transit line with interchange stations would overcome this objection. It is worth noting that the first two of the London 'tube' railways to be built (the City & South London and the Central London) also have tunnels with a steep gradient leading down from a station and another leading up into it, the object in this case being to save power in acceleration and braking wear and tear when stopping. The majority of 'tubes' built later do not have this feature so apparently it was not considered to be worth while. This did not stop the Rotterdam Metro, opened to traffic in 1969, doing exactly the same thing for the same reason. The gradients occur on the open sections of the line where it runs through the streets on a viaduct. The stations are some 40 to 50 feet high in the air while the line sweeps down on both sides to a viaduct that is only 25 feet or so high.

AUTOMATIC TAXIS

The title automatic taxi has been coined elsewhere roughly to describe a new form of guided transport that has appeared within the last decade or so, or rather many systems of this description have been proposed, especially in the United States, but none so far have had a practical application. The Rohr Corporation monorail system with six-seater cars mentioned previously properly falls under this heading; the provision of automatically-controlled vehicles with the capacity of a taxi or a minibus running on some form of track. What the promoters propose is similar to a driverless automatic railway, with some of the problems removed because construction is much lighter and speeds are relatively low. The development of automatic taxi systems stems from the success of motor-car transport, which has spread the suburbs of cities far and wide over the surrounding countryside. At the same time the very success of this form of transport has brought traffic congestion problems to the city and thus difficulty of access to it, this in turn leading to the development of minor centres in the suburbs. The development of minor centres has altered the traffic pattern; in place of movements into and out of the city centre the requirement now is for movement between a multiplicity of small centres, the old city centre often being just one among them.

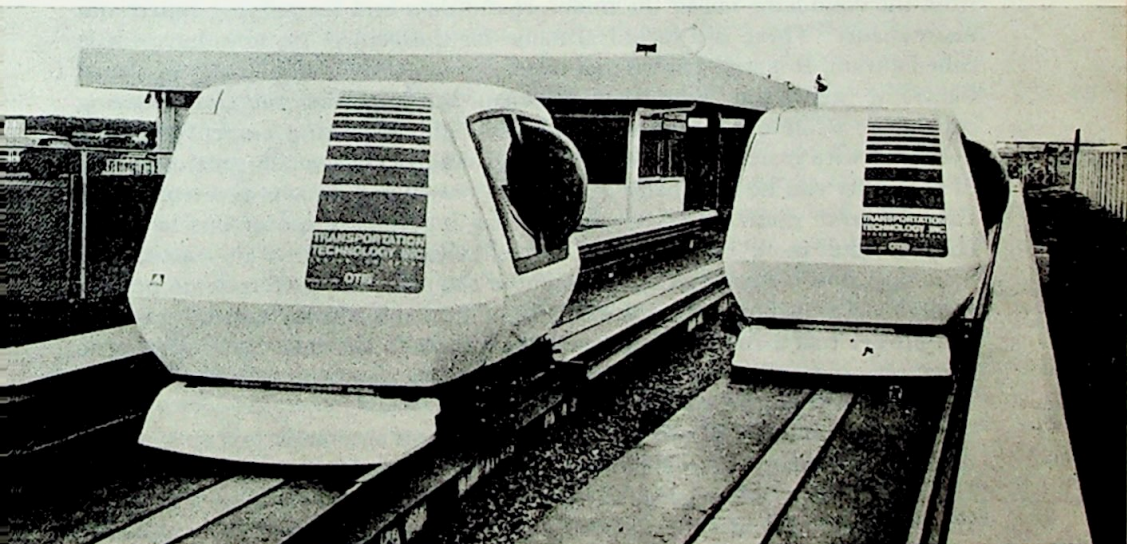
The development of the extended city with many small centres is built on the flexibility of road transport, in particular the motor-car for passenger transport. But there are disadvantages; many extended cities are now finding that the level of passenger transport required is so high that traffic congestion and delay is the end result. Furthermore the old, children and the poor either do not have or cannot use motor-car transport and in the extended pattern of urban sprawl these people tend to be marooned in their own neighbourhood, with their radius of action limited by the distance that they can walk. Hence the demand for a public transport system separated from road congestion yet with capital costs low enough to make a living from the low traffic flows likely in the relatively thinly-populated areas of an extended city. Such a demand is quite familiar and has been met in the past by the development of the tramway and the light railway among the guided transport modes, both now ruled out by their high labour costs unless fully-automated. Automatic taxis without drivers are a modern version of the light railway and indeed some systems have the characteristics of a portable light railway in that they can be readily dismantled. All systems envisage high level transport so that they can be built above existing roads, but even so the viaducts are so light that they can be taken down and be re-erected elsewhere if a route does not produce enough traffic. Lightness too makes for low capital expenditure and possibly this will ensure cheap fares—although it should be noted that the very title automatic taxi does imply that the fares may be above the level of a motor-bus.

Apart from some monorail systems, the automatic taxi systems developed typically have rubber-tyred cars guided by some form of reinforced concrete rail and they include British, Italian and Japanese systems as well as those of the United States. Most cars are driven by conventional electric traction motors but there are systems using air pads for support and linear motors for traction—already in the development stage the inefficiency of the linear motor at low speeds combined with the expense of blowing the vehicle off the ground have given rise to grave doubts about the operating costs of these latter. Organisation of these automatic taxi systems envisages not only out and home lines but a complete network of interconnected routes. A wealth of electronics will not only drive the cars but also route them. All this will be based on a central computer and the techniques proposed are similar to those described in Chapter Six for automatic railways, except that track circuits will not be possible. In order not to hold up cars running on the main line the stations will be sited on loops and the usual intention is that the passenger during or after paying the fare in an automatic machine will press a button that will inform the central computer of his presence and his desired destination. The computer will note the call, find the nearest empty car and after the passenger has been picked up will route the car to the required destination. All this brings up the question of points and numerous solutions are proposed, the majority in effect giving the car a nudge in the required direction after which it is caught by a fresh set of concrete guide rails. One of the air-pad supported systems uses an arm on the car, which will stretch out when

required to engage with a curved guide which will pull the car over on to a new track. This same system dispenses with station loops, the car will stop on the main line and then at a signal from the computer move sideways to dock at a platform off the track.

One of the Japanese automatic taxi systems proposed is intended to run through city streets on the road surface and provides for four-seater vehicles, which would be guided and driven from a linear-motored trolley running in a duct below the roadway. Being a city system the promoters are anxious to show that they can carry large numbers of passengers. To give a maximum passenger capacity they propose to run their taxis so close together that should one stop suddenly for any reason (such as a collision) it is inevitable that many taxis in the rear would crash into it at periods of maximum flow. This is because the taxis must run so close together to keep up the capacity that the vehicle ahead is well within the rear vehicle's braking length. Quite a number of the automatic taxi systems being described here propose a similar close spacing, which is frowned upon by those brought up in the orthodox duorail tradition that in the interests of safety any train should be able to stop before meeting a likely obstruction. The counter view, which would allow vehicles to run so close together that 'shunting' collisions are likely should one of their number come to grief, bases its argument on the likely results to the passengers. Say one of the Japanese line vehicles is in collision, the two occupants killed and 20 more injured as a result of the following vehicles crashing into the obstruction. At four people per vehicle the total capacity of all the vehicles involved would be say forty. A large vehicle could be provided to give this capacity of forty and to meet safety

Air-pad suspension and linear-motored experimental automatic taxi in the United States



requirements would run at a respectable distance behind the vehicle in front so that it could stop in case of trouble. But should the large vehicle itself be involved in a collision the likely result would be two people killed and 20 injured, just as above. Nothing is gained from the safety point of view, or so runs the argument, jesuitical though it may be. What public opinion would make of the argument remains to be seen. In Great Britain for the time being public opinion tolerates 'shunting' collisions and the results in killed and injured when they occur on British motorways in foggy weather. It may be that similar tolerance would be extended to automatic taxi collisions when the taxi systems run on road surfaces, as in the Japanese proposal, but it seems more than probable that the tolerance would not extend to similar collisions on automatic taxi systems that owned their own right-of-way. Public opinion is often quite irrational.

The desire for the largest possible maximum traffic capacity for the automatic city taxi system proposed by the Japanese is possibly an indication that the system is being proposed for an improper application. Because it is to be used in a city and this high maximum capacity is desired one can have a little economic fun with the promoters. To start with, operating costs could undoubtedly be cut by doing away with linear motor propulsion, as orthodox electric traction motors to drive the subterranean trolley would be cheaper at the relatively low speeds. Next of course if maximum capacity is really the aim larger vehicles should be used, indeed if the demand is there at taxi fares the profits would go up enormously, probably fare reduction would bring in even more traffic. The trouble is that larger vehicles would be heavier, so heavy that guidance from under the ground would be difficult. This could be simply overcome by laying guide rails suitably sunk into the road surface. If the guide rails are on the road surface there is no reason why the traction motors should not be put upon the vehicle itself, fed with current from the conductor rail in the underground duct and simplifying repair and maintenance. There is a technical name for the vehicle we now have—it is called a tram. It is well-known that trams diminish the total capacity of a road for traffic (expressed in terms of vehicles), but by giving the tram steering capability, while abolishing the guide rails and collecting current from an overhead wire instead of from an underground duct, a much greater degree of flexibility can be obtained—the vehicle now being known as a trolleybus. Experience in many cities has shown that an ordinary motor-bus is rather cheaper and more efficient than a trolleybus. Of course in maximising passenger flow we have rather lost sight of the man who prefers some privacy in personal transport and requires it to be available almost instantly, but he can always hail a road taxicab. So we are back to the state now existing in Japanese cities, all ready for a fresh promoter to come along and propose an automatic taxi system.

Curiously enough no one has come up with an automatic taxi system that would solve many of the guidance, command and points problems—the laying of light, narrow-gauge duorail track. Duorail would allow the use of track circuits to detect the position of cars instead of the rather complicated

electronic sensors now used and its capital cost would be no more than the strangely-shaped reinforced concrete sections used for guidance. There are as it happens two good non-technical reasons for this neglect of duorail advantages. Automatic taxi systems have to be sold to governments and city fathers and the sales pitch is that no city can afford to be without an up-to-date, electronic, futuristic and efficient transport system. Any technical feature that can result in the old-fashioned term trolley-car or tram being attached to automatic taxis will kill the sales and public relations campaign stone dead. Public opinion can be irrational and city fathers and even governments have to pay some attention to it and meet the demand for the latest scientific marvel, even if it does cost a little more. Secondly, the engineers behind the ten or twenty systems so far devised, as well as the back-room scientists, are part of the public and share its taste for the latest fashion and in addition they have a direct interest in doing something entirely new. Out with the old and in with the new is the feeling, even although a lot of hard-won knowledge is lost in the process. As an example, one system was troubled that too many people might crowd into one of its little cars. With a wealth of electronic ingenuity such overloaded cars are detected before they can move off and with more electronic ingenuity a disembodied voice tells the passengers that some must get off and that there will be another car along in a minute. This sort of thing will be readily recognised as the brain-child of a truly innocent scientist, a man who never in his life has seen a crowd of season-ticket holders storming a train hell-bent on their homes and wives. Even if some passengers do get off it will be after possible bickering and certainly after a prolonged delay to allow the effects of moral disapproval to take hold.

Application of the automatic taxi systems devised awaits the identification of suitable sites. The passenger flow must not be such as to go beyond the maximum capacity of such systems at any time, some 6,000-10,000 persons per hour, nor must the traffic be so meagre that it could conveniently go by road. In the United States it has been calculated that only six cities have passenger flows in excess of 10,000 people per hour on any route, so perhaps the upper limit is not so important. In contrast, European metropolitan railways find passenger flows of 25,000 commonplace and the maximum on one or two routes can reach 50,000 or even more. The contrast arises because the cities of the United States are based to a far greater extent on the motor-car, which has the low maximum passenger capacity of 3,000 persons per hour per traffic lane. In effect, United States cities have been forced to cover large areas of ground because of the ineffective nature of the transport mode selected, the motor-car. Here lies a source of future difficulty for automatic taxis, for having established itself and succeeded a system may be faced with more traffic than it can handle. The fact of success will have demonstrated that it is a superior passenger travel mode to the motor-car and hence people will wish to live and work in the area which it serves. More people mean more passengers and hence eventually the outmoding of the automatic taxi. Cities are not sited by chance, they stand where they do as the result of

physical geography and complex economic forces and it can be argued that because they selected the motor-car, a mode of transport which is unsuitable to their real needs, they have been forced to extend over surrounding areas. Regarded in this light the automatic taxi may pick up traffic for another reason too, they will be correcting the distortion caused to normal economic forces by road transport. Properly used it and the rapid transit line may be powerful tools in the hands of the planner to resuscitate city centres, the decay of which is a source of worry today in the United States. Transport as a tool of government in this fashion will be discussed in the last chapter.

AUTOMATIC ROAD TRANSPORT SYSTEMS

What is road transport doing in a chapter devoted to guided transport modes and in a book called *Future Railways*? The answer is that once exterior guidance of road vehicles is attempted they are in effect guided by a railway. The track used may only be composed of radar beams, but track it is and its use brings in its wake all the familiar problems of guided transport management. Automatic road guidance is only a matter of experiment as yet, the object being to make a road vehicle automatically follow a radar beam in the same manner as an aircraft pilot follows a radar beam for a safe landing. At the same time electronic signals must provide for the vehicle to accelerate and decelerate as required. All this has been done successfully enough for individual motor-cars and it remains now to try out the system for a crowd of vehicles on a motorway or other road. Unfortunately a major snag has cropped up, most owners of motor-cars and many owners of vans and lorries keep their vehicles in such a deplorable state of repair, particularly the brakes, that it would be unsafe to run them under automatic guidance control. It might have been added that the slap-happy way motor-cars are assembled in many factories is no help either, but as the people interested in automatic road transport systems are motor manufacturers this aspect is understandably not dwelt upon. What the people conducting the experiments are up against of course is the great dichotomy in public attitudes. As long as an individual man is in charge of a road vehicle, public opinion will allow him to kill himself and others by the thousand every year. As soon as a company, local authority or government takes a hand and provides a guidance system public opinion swings right round and calls vociferously for a nil mortality rate.

The object of automating road transport is not to save labour, the driver will still be in the vehicle to take over when the automatic section ends. The object is to make the road carry a greater number of vehicles, either by closing the moving vehicles up to one another or by higher speeds, or both. The probable effect of a successful system will be that more vehicles will be carried on an existing road and the capital expenditure necessary for widening it will be saved. An immediate difficulty will be apparent to all students of transport, the individual owner of a vehicle will have to foot the bill for extra apparatus

on board (or at least part of the cost) whereas the major profits will appear in the hands of other people, the government will save on road capital costs, the public will possess more greenery and be burdened with less concrete and so on. Another difficulty for promoters of such roads will be the marginal expenditure nature of so much motoring, that is the motorist will know that he can get from one point to another in any case and will see no reason why he should pay extra to get there a little faster by automated road. The way round this is to make the automatic road 'free' to all and load the cost on to the government. The road will not be free of course and its cost will show up in increased taxation of all motorists, but the promoters of automatic roads can get round that by blaming increased taxation on government inefficiency or the effects of inflation or some such story.

Those who devise automatic road systems are good at quoting figures to show what a large number of vehicles can pass a given point in a given time when automatically controlled, but they tend to be very unforthcoming about terminal problems. To provide the great number of vehicles required for maximum flow there will have to be a pool of vehicles at the start (i.e., motorists will have to queue up for a time) while at the other end motorists can hardly be simply shot off the end of the track. The immediate reaction of a driver on regaining control would be to stamp on the brakes because he would be going too fast and be too near the vehicle in front. Should he do this the vehicle behind will collide with him and there will be collisions of this sort all the way back for miles. Which brings up the question of points to shoot off the vehicles in a number of directions on leaving the track. Little is said about points either and even if they can be devised and provided there would surely be a number of drivers each day who would fail to take over control of their motor-cars again in time. They may have fallen asleep, let their minds wander or be fighting a wasp trapped in the saloon, the actual cause does not matter but the operator of the automatic track would get the blame for the subsequent accident. Multiple points to lead to a large number of terminal stations where the vehicle would be automatically stopped before going on under the control of the driver might be the answer, if satisfactory points can be arranged. Even so, multiple terminals would require a great deal of land and this might be difficult to acquire in a city.

Another proposed way of automating road traffic is to allow motor-cars to drive on to a moving platform and then bring the vehicle to a stop. The platform (running on rails or a roller track) would carry the vehicle through the countryside until the driver wished to leave it and go on under his own power. Organisation would probably be easier than the radar beam railway but unfortunately it can be calculated that the movement of the platform would require so much power that the whole operation would be quite uneconomic. A very good moving platform system for road vehicles exists in every country here and now, there is nothing to stop motorists and road hauliers putting their vehicles on a railway train and having them conveyed to where they wish to go. What stops them is the cost, and if cost stops them now why should anyone suppose that the same people would be willing

to use an automated road if constructed? Another use for moving platforms is to convey pedestrians and some of these are in use here and there and have been for a considerable time—moving pavements is another title for them. The leading British authority on moving pavements has stated that they are uneconomic unless they can carry 30,000 people per hour, that is about the number of people that use the pavements of a busy shopping street at the height of the pre-Christmas peak period, as for example Oxford Street in London. It appears likely from this that moving pavements will only be installed where there is some other object than merely moving people, as a public relations exercise for example.

The guided transport systems that have been described in this chapter are so various that it is a matter of some difficulty to sum them up. All of them are attempts to carry passengers and sometimes goods more cheaply than the existing duorail or road transport modes, but all tend to lack the flexibility of these modes and thus can be expected to be confined to more or less specialised applications for restricted use. As specialised transport they will have to show that they are economic before they can be fitted into the general transport pattern. Meanwhile, because the modes are new and employ new techniques it should not be assumed that gee-whizz guided transport is necessarily better than older methods. Indeed, some of the new modes are leading themselves astray by asking the wrong question. They ask, 'How shall we use our new method or invention for transport?'. Maybe that the new method or invention has obvious transport applications, but the proper question that should be asked is, 'We have a transport problem, what is the most economic method of overcoming it?'. Possibly all the research, innovation, application of new techniques and sheer hard work that is now going on may give better answers to this latter question in due course.

CHAPTER EIGHT

Transport organisation

This book has been primarily concerned with the technology of moving passengers and goods by guided transport, in particular by the duorail mode. That other guided transport modes have had less space devoted to them is because the technology has yet to be developed and because many of the duorail techniques are equally applicable to the other modes and are adopted by them as required. Nevertheless, in spite of the concentration on technology it should never be forgotten that all the ingenuity and all the skill are only a means to an end, the movement of passengers and goods in considerable quantities from place to place. Should the traffic not be there or should it be flowing in such lesser quantity as can conveniently be carried by the road transport mode, guided transport can be dispensed with. Determining traffic flows and thus those routes on which guided transport can be usefully deployed is a matter for the national government in all the countries of the world. Everywhere the final authority for trunk railway and other guided transport modes is in government hands, just as trunk road transport is in the final analysis government-controlled and as air line routes are government-authorised, in the latter case by international agreement where necessary.

This universal national government control of transport is no accident, it was long ago seen by politicians and statesmen that transport is a powerful instrument to enforce national government policy in its own right. This role of transport in government may not be so evident in a developed country such as Great Britain, where increasing traffic leads almost automatically to road widening to accommodate it and where 'public demand' can cause the retention of an uneconomic branch line railway. Nevertheless, the power is there to build up or depress this or that area by the provision or non-provision of transport. Developing countries offer the best examples of the power of transport as a government instrument. In these it quite often happens that a conscious decision must be taken to use available money to build a road into province A and thus increase the standard of living of the population, or alternatively run the road into province B and leave the inhabitants of province A to poverty. Nor is the use of transport to control development entirely unknown in the British Isles, grouse moor owners in Scotland are reputed to

have discouraged road building through their estates in order to preserve the privacy of their birds.

Great Britain as a pioneer of railway transport evolved national control of transport from 150 years ago or more, building on parliamentary legislation that had authorised the activities of canal and turnpike road companies. Acts of parliament were necessary for these companies (as later for railway companies) to give them the power to acquire land compulsorily if the owner was not disposed to sell. Conditions were often attached to these acts of parliament, conditions that were later codified for railways by successive Railway Acts. Among other things the Railway Acts insisted on the preparation of railway company accounts in a standard form, gave the government a final say in the rates and fares to be charged and insisted on a minimum train service and on minimum safety requirements. In return the companies were not only given authority to build a railway route but were protected from the competition of other railways and other transport modes. Reliance was placed on private entrepreneurs and their capital to get railways built in the right places, but there were doubts about this in some quarters. Mr. W. E. Gladstone, who piloted railway acts through parliament in his capacity of President of the Board of Trade, prudently included clauses in the 1844 Act that provided for the nationalisation of railway companies should matters not go as the government wished. In the event the explosive prosperity of nineteenth-century Great Britain made these nationalisation clauses a dead letter, there was plenty of capital available for building all the railways that could be desired at home and a great deal over for building railways abroad, notably in the United States and in the Argentine.

In most other countries in the world private capital was in relatively short supply and railway building was financed by the state, or companies were subsidised by the state, in order to ensure that what capital was available was expended where most needed and in the most economical manner. The railways were often operated by the state as well and many different forms of organisation were evolved, all the way from building and operation by a government department to building and operation by a company in which the government held a controlling interest. A popular method at one time was the building of the way and works by the government, which then leased its railway to a private company which equipped it with motive power and rolling stock and made what money it could. The British Parliament, whatever it did at home, was no stranger to state control, for many years in the late nineteenth and early twentieth centuries it ran more directly-managed and state-owned railway route mileage in territories outside the United Kingdom than any other legislature in the world. Whatever the organisation used, every country in the world retained ultimate authority for the fares and rates charged and for safety matters in the hands of the state. Not only did all governments wish to ensure that transport was available on equal terms to everyone but above all they wished to ensure that transport was as cheap as possible, in order to promote the general prosperity and welfare of their country.

Originally, railway rates and fares were fixed by the governments concerned to give a modest rate of return on the capital invested. Except in the case of private railway companies, which were in a position to make some protest, politicians soon perceived that they had the power to hold transport costs down by adjusting rates and fares. When they did so they took care to draw the attention of those they represented to the favours that they were doing. The resulting railway operation deficits were made up as quietly as possible out of general taxation afterwards. In the upshot there is scarcely a railway administration over the world today that does not run at a substantial loss. Given that cheap transport is to the national benefit, who is to say that this is wrong? In effect, the railway organisations have been drawn into the normal government duty to see that the wealth created by the mutual efforts of rich and poor is equitably distributed. The same tendency is to be seen in the handling of road transport matters by the various governments, the usual organisation being for the government to supply the roads and to collect the costs from the users in the form of taxation. Recent studies in Great Britain have shown that heavy lorries and motor buses are not paying their fair share of road costs in that country. No doubt this has come about fortuitously because modern vehicles are heavier and faster than their predecessors and thus cause more road surface wear and tear. The effect is that road hauliers and motor-bus operators are being subsidised by those who drive motor cars for pleasure and convenience, as well as by local taxpayers. No doubt it would be possible to adjust the taxation rates, but once more who is to say that the subsidy now allowed is wrong, given a national aim of cheap and convenient transport? Similar studies in France and Austria have revealed that heavy transport is seriously undercharged in those countries too.

To taxpayers in Great Britain the statement in the previous paragraph that heavy road vehicles enjoy a subsidy may be a surprise, especially in view of the oft-repeated information that only part of road taxation is actually spent on roads. The catch is in the word spent; although much of the local and national government road expenditure is of a capital nature no interest is charged on this capital, it is written off forthwith. In order to compare like with like it is necessary to include interest charges in the total costs of both rail and road—the alternative proposition that government capital expenditure is somehow interest-free would mean that British nationalised industries have been making unperceived and rip-roaring profits for many years. Adding the interest on the capital locked up in roads to the annual expenditure on them brings total road costs nearly to the amount collected in road taxation. Apart from direct road costs some compensation must be paid for the damage road vehicles do to the environment and thus the total cost outweighs taxation and there is a subsidy—a subsidy that is all the greater as there is a school of thought which regards some road taxation as general taxation and not to be thought of as a contribution towards road costs. A heavy vehicle subsidy on these lines has been going on for many years in Great Britain and is as natural as the air they breathe to the business men involved. Nevertheless, any government when laying down the transport framework in which

business men operate must set all subsidies on one side. Only then can the most economically favourable mixture of transport modes be determined to meet the needs of the country concerned.

All this is very confusing to the simple-minded business man, who believes that if everyone does his best the competitive cut and thrust of the market place will ensure the most efficient running of affairs. The simple-minded business man who enters road haulage often finds that he can readily undercut railway rates and thus comes to believe that he is more 'efficient', regardless of the fact that the railway rates he competes with may have been set at an artificially high level in order to compensate the railway for unprofitable traffic which must nevertheless be carried. Again, the simple-minded business man can see for himself a number of railway operations that are clearly unprofitable and thus condemns the railway management for 'inefficiency', again in happy ignorance that government policy compels the railway to go on doing things that it knows very well are quite uneconomic. In 1965 an Italian parliamentary commission found that about one-quarter of the railway system was performing no useful public service. Despite this finding the politicians have not allowed any closure of railway routes, presumably because of vociferous local opposition from people whose fathers told them that railways brought prosperity and who have not noticed that times have changed. All that has happened is that on a tiny fraction of the route mileage passenger services have been withdrawn in favour of motor-buses.

Competition between railways, or between railways and other transport modes, has rarely been recognised at government level as a satisfactory way of doing things. The reason is that no country in the world can afford the enormous fixed capital costs that have to be sunk in transport before it can function, unless the capital continues to earn its keep. In theory a railway and a motorway can be built to compete between two cities and let the best mode win. In practice the irrecoverable capital locked up in the earthworks, bridges and roadbed of whichever mode is vanquished and abandoned represents such a heavy drain on a country's resources that it cannot be allowed to happen—a point recognised by Mr. W. E. Gladstone when introducing his 1844 Railway Act as well as by the eminent economist of the period John Stuart Mill. Each country therefore has evolved over the years its own transport planning machinery to ensure that money is spent wisely and not wasted. These planning procedures differ between countries and it is easy to pick holes in the methods of any particular country, but nevertheless on the whole each suits the national characteristics and mentality of the country concerned. Some countries are empirical, the civil servants or the parliament decide each case on its merits, other countries assiduously collect statistics (often rather shaky statistics) and decide cases on the figures before them, others again draw up five or ten year plans, often following them out to the letter regardless of what has been happening in the interim. As has been said, each country follows its own methods of transport planning with the overall aim of wise and efficient government of the territory as a whole.

Planning, the intelligent forecasting of economic and other conditions in the

years ahead, is a good deal more difficult than reliance on market forces and competition and our simple business man is apt to regard planning procedures with some suspicion. But to do our business man justice, he is no fool. As soon as he is in charge of a business that is a cut above a corner shop the idea of competition internally within the firm goes out of the door, a happy and co-operative staff is recognised as a business asset. This raises the problem of measuring the efficiency of the firm and a host of business criteria have been evolved, based on all sorts of management tools from cost accounting to management-by-objective. A recent book by an economist has applied these business efficiency criteria to British Rail (which knows all about them anyway) and has demonstrated that British Rail management is superior to almost any other in the country, which should be good news to everyone. Large businesses now indulge in what is known as corporate planning. In effect it has been found that plotting the future course of the business is too important to be left to the company directors (who have not the time to do the job properly and rarely have sufficient information) and forward planning has been taken over by management. Corporate planning is of course just what has been done by government planners for one hundred years or more. In short, planning transport is no different to what is done in any business concern of any size, it is merely on a larger scale.

Handling all the necessary statistical material for planning purposes is facilitated nowadays by the advent of computers. Formerly transport statistics were often simplified and under few heads because of the sheer difficulty and cost of dealing with the mass of figures involved. Now the computer does the work and a more accurate and effective decision base can be prepared. As an example a study now being carried out in Hungary can be cited. Hungary has yet to use road transport on a wide scale, firstly because it was often cheaper to build a railway across the alluvial plains and secondly because of the poverty of the country. Now the flexibility and economy of the road mode for short hauls is recognised and the Hungarian State Railways needs a plan to provide for the change to road and for the closure of branch lines, lesser stations and minor goods depots. Marshalling yards and locomotive depots as well as the branch lines and stations are all earmarked for closure as roads are built and the plan takes into account the availability of road making plant, materials and labour, as well as the output of the Budapest bus and lorry factory. Even the national policy of decentralising factories away from cities plays a part in the overall scheme. Assembling all the diverse data and drawing conclusions from it would have been next to impossible without the aid of the computer.

An even more sweeping transport study has been going on in the German Federal Republic since mid-1969, the full conclusions of which have yet to be published although the results are known in broad outline. The plan is based on the national forecast of economic development and population trends that show that sometime between 1975 and 1980 both the road and air transport internal modes will be saturated with traffic. Saturation is taken to mean that any further expansion of these modes to meet transport demands would be

at the cost of quite unacceptable damage to the environment, i.e., as the government has a duty to protect the prosperity and wellbeing of the inhabitants of the country it has laid down that these modes will be harmful above a certain level of traffic. This being so, how is the expected increase in passenger and freight traffic to be carried? The report will recommend the construction of a high speed guided transport network between the main centres of population in the country, with particular emphasis on north-south traffic. This network will be separate from and complementary to the existing railways (which in addition are building high speed lines of their own) and will provide for the carriage of lorries and motor cars (the so-called piggy-back or kangaroo traffic) as well as passengers and containers. All to be carried at average speeds in the region of 250 mile/h. Both the duorail and the magnetic levitation modes are being considered for the network. While the former may not be able to reach the highest speeds required (or so the Germans think) its adoption appears likely as magnetic levitation may not be developed satisfactorily to meet the urgent need for transport in time. It will be interesting to see what sort of legislation is evolved to restrain the activities of road hauliers and motorists in support of the plan.

The proposed guided transport network for Germany connects up neatly with a study that British Rail was reported to have made a few years ago on the best method of running an automatic railway, a study that was akin to the army 'tactical exercise without troops'. The result was the recommendation that every coach and wagon should be equipped with traction motors and run over the railway as a separate unit. In operation a wagon, standing say in a Glasgow siding and destined for London, will be given a label that can be read electronically by lineside scanners. When all is ready a man on the platform will press a button on the wagon, which will pass the signal to the local computer signalling installation via an inductive communication system that the wagon wishes to start. The computer will set the road and start the wagon off automatically. On an electronic scanner reading the destination the computer will route the wagon in its area and send a message to the next computer signalling installation, say at Carlisle, that a London-bound wagon is approaching. The Carlisle computer, advised of all the coaches and wagons approaching it, will work out optimum timetables for them all through its area and see them on their way, meanwhile advising the next computer signalling installation, perhaps at Preston, that a London wagon was approaching, and so on. Eventually the wagon will run into the required siding at London and stop automatically, just as all the stops and starts along the route were automatic. Should British Rail adopt this scheme it is likely that automatic wagons would run among ordinary trains at first (controlled by signalmen as well), but the suitability of the findings for running the proposed German network will be recognised.

Enough has been said to show that transport organisation in each country is a political matter. To analyse further to show how decisions are reached and what determines the division of resources between the various transport modes would be a fruitless exercise in a jungle of party politics, whichever

particular country was selected. Each country has its own approach to the transport problem, in each there is a different public attitude to the government's handling of transport and in each the present position is based on a different historical background. All that can be usefully said perhaps is that the actual rates and fares charged by all the various transport modes in every country rarely if ever correspond to the true cost of the service provided—in so far as that true cost can be determined. Transport is international and while each country determines its own transport policy due regard must be had to the effect on adjoining countries. As an example, in Great Britain it is a general rail policy to encourage the loading of freight in complete train loads and to try and discourage the loading of individual wagons to and from diverse destinations. By this means it is hoped to cut the sorting and marshalling of wagons to a minimum and so to cut transport costs. In the rest of Europe on the other hand, the wagon load is still the norm and railways encourage the loading of wagons from industrial siding to industrial siding, if not from goods yard to goods yard. With the opening of the Channel Tunnel and the increase of rail-carried freight traffic to and from Great Britain which of the two policies will prevail? In the long run what the traders using the railway prefer will supply the answer (always supposing that what the traders want is not against public interest) and if the exporters to Great Britain and the importers from that country continue to favour wagon load quantities, British Rail will have to conform. The planners and the economists will have to forecast the future and decide on the policy against the information they have.

Nevertheless, the planners and economists are not right every time and often it is possible to criticise their decisions. It will be recalled that much road traffic is expected to pass through the proposed Channel Tunnel and that this will be ferried by train. Terminals for loading and offloading this road traffic to and from rail are to be sited close to each portal of the tunnel according to present plans. Indeed the terminals are so close to the portals that rail interests are complaining that the trains will have no chance to attain optimum speed before entering the tunnel to allow maximum traffic throughput. In view of the German concern about the ruinous effect road transport can have on the environment it does seem extraordinary that once the road vehicles are loaded on a train the opportunity is not taken to carry them as fast and as far as possible. It is submitted that the great bulk of the motor cars and lorries to be carried are for destinations away from Kent and the Pas de Calais and that this being so it is suggested that the proper place for tunnel terminals in the first place is London and, say, Lille. Local traffic wishing to cross the English Channel can be conveniently carried by the existing sea ferries. Later on with the same objective of avoiding road congestion and unpleasant living conditions, terminals might be sited farther afield, Paris, Brussels and even Düsseldorf on the one hand and Bristol, Birmingham and perhaps Manchester on the other.

Such a scheme for the carriage of road vehicles by rail to avoid pollution of the environment will be costly, new railways will have to be built with tunnels,

overbridges and other works of a convenient size to allow the vehicles to pass while loaded on suitable wagons. It is to be noted nevertheless that earlier in this book it was recorded that a new railway from Paris to Brussels with a branch through the Channel Tunnel to London is planned in any case. Transport decisions of the sort required must come from the governments in this case, together with the necessary funds, for it can be expected that there will be little support from vested interests. The railways concerned will rightly point out that the traffic to be expected for many years will not pay for the interest on the vast sums required for the new works, even if the expenditure is only additional to that proposed for a new and profitable railway. Motorists and road hauliers will protest loud and long at being forced to take a train inland at a greater cost to themselves than the fuel necessary to get them to the coast. Others too will no doubt complain that their lives are being turned upside down. Those who benefit will keep diplomatically quiet as always, especially as the main beneficiaries financially will be local governments and the national governments themselves. The suggested arrangements will benefit motorists and road hauliers too, as rail transport is faster they will have the use of their vehicles in one country or another for several hours longer than they might expect otherwise. Furthermore, should road hauliers arrange for pools of drivers to deliver and pick up road vehicles at either end of their journey, instead of the drivers accompanying their vehicles, they will be on the way to saving a substantial sum in wages—remembering that no road haulier is going to thank anyone for reorganising his business in this manner. As with many other transport matters the governments concerned must take a conscious policy decision in this case, should they feel that the environment and the living conditions of the majority of the people they are responsible for will be enhanced, regardless of the outcry from those who will be upset.

Another transport innovation which is causing a great deal of commercial trouble, which on occasion surfaces as political trouble as well, is the general introduction of containers for carrying all sorts of goods. On land, containers are an ideal load for a railway provided the length of haul is long enough. For shorter distances road transport will be preferred, for the cost of loading and unloading containers to and from rail will outweigh any gains from the cheaper rail haul. On the whole the problems of handling containers by the various transport modes, road, rail and sea, have now been mastered, as have the problems of interchange between modes. The real difficulties of container transport now lie in organisation outside the strictly transport field. As an example, the British government with commendable foresight a few years ago established an inland customs post at Birmingham. This was to clear containers arriving from abroad, it being envisaged that the containers would pass straight from sea to land transport at the ports as that would ensure maximum economy in transport. This inland customs post is now closed, because the journey of containers is organised by shipping agents and forwarders who have offices at the ports but not in Birmingham. Few containers reached Birmingham for these people insisted on them being put aside at the ports for

their check, as they had been accustomed to check goods before the arrival of containers, and while the containers were standing at the ports they were given customs clearance just as before. The convenience of the old order of things was put before speed and economy of transport. In time the customers of transport will perceive where they are losing money and nonsenses of this sort will be cleared up. One solution that is being actively pursued is for the various transport modes to get together and offer to handle containers throughout including customs clearance from door to door, eliminating the now unnecessary shipping and forwarding agents altogether.

As far as railways are concerned an interesting development brought about by containers is a reversal of the old idea that carriage of goods by sea is cheaper than carriage by land. Apparently a specialist container ship can make optimum profits by short sea voyages, even when the rate charged per container is so low that the cost of a longer land haul can be added on and still show a saving in transport cost to the owner of the goods. Ships will no longer seek ports as far inland as possible and European Atlantic ports will now, for example, be sited at such places as Vigo in western Spain, at Brest in Brittany and at Falmouth in Cornwall. The long overland hauls from such ports to the centres of population will be good rail traffic. It might even be cheaper to land a container going from the United States to Holland at Falmouth and take it by rail to one of the flourishing container ports on the North Sea for loading on to another ship. All this is part of the container revolution in which railways will have a role. Some of the more obvious land short cuts are already operating. For the past few years the Soviet Union Railways has been collecting Japan-bound western European containers at Leningrad. From there they go by rail to Nakhodka on the Sea of Japan north of Vladivostok for a ship, the Europe-Japan transit time being cut by nearly one half. The Soviet Union Railways has also been round western Europe looking for container traffic to Persian Gulf ports as well, the idea being that they will be handed over to the Iranian State Railways on the frontier between Azerbaijan and Persia.

It will be noticed above that the Soviet Union Railways collects western European containers at Leningrad, at which port they arrive by sea. When the traffic first started containers were sent by rail into Russia (some still go in this manner), but it was soon found that the container wagons took as long to get to Russia as they did to cross both Russia and Siberia. The reason was partly because the wagons had to pass through marshalling yards, but even more delay was caused because on a journey from say Holland no less than four international frontiers had to be crossed. Wagons at frontiers are shunted into customs yards where they wait for the customs officers to walk round and give them clearance. Sometimes the customs officers get the railway to sort out odd wagons from the sidings and to shunt them into the customs sheds for a close inspection of their contents. All this sort of thing takes a lot of time. The International Union of Railways is now engaged in talks with all the governments of Europe about customs procedures, for the railways wish to run fast international liner trains carrying containers. These liner trains will work to a strict timetable and will run each day whether or not they have a full

load of containers. British Rail was a pioneer of container liner trains for internal services and has a hand in the international services. Other European countries are beginning to run internal liner trains and an international service has started between Paris and Cologne. Customs inspection is the bugbear of these international trains, for example Milan to Vienna could be run in ten or twelve hours but not if the train has to stand at the frontier between Italy and Austria for a day or so. So the railways are asking for customs posts at the starting and terminating points of their liner trains (rather in the manner the British government supplied a customs post at Birmingham). Such posts will enable liner trains to cross international frontiers non-stop if required. Alternatively, the railways ask for very much accelerated customs formalities at the frontiers within a booked time.

Given simpler customs procedures the railways of Europe plan a network of container liner trains and can start to think of sending containers into Russia on a regular basis. A liner train service to Nakhodka from western Europe running to a timetable could probably cut off several days from the journey west to east and vice versa, with even greater economy for traders. As for the Persian Gulf, a southern railway route exists running across Yugoslavia, Greece and Turkey to reach Persia. Even more interestingly a United Nations report has recommended the construction of a railway linking the Iranian State Railways with the Pakistan North-Western Railway. Should this line be built across about 150 miles of Baluchistan desert it will be possible to put European containers down on the shores of the Bay of Bengal in perhaps half the time and at less cost than if they were dispatched by ship. Mr. F. S. Williams, a pioneer in writing popular railway books such as this one, published *Our Iron Roads* in 1852 and in it he devoted a page or two to the prospects of a proposed 'Great Eastern, Euphrates & Calcutta Railway', mainly having in mind tourist traffic between London and India it must be admitted. Another 150 miles of railway building across Mr. Williams' 'Beloochistan' and the dream of 1852 will be realised for another purpose entirely. How a container service might be organised from Europe to the east is another matter, for a considerable investment will be required in container cranes and other plant in unlikely parts of the world. One possible suggestion is the formation of an international shipping line consortium to provide capital and to hire container trains, running from say Rotterdam to a Persian Gulf port. A shipping consortium is suggested because it would be in a position to produce the necessary ships at each end for onward transmission of the containers if required. The more international the consortium the better, so that they might always have a man of neutral nationality on hand to negotiate during the petty squabbles that spring up between nations and thus to keep the traffic moving. For instance, an Englishman in 1972 would not be the person to send to the Iraqi State Railways to get them to take over containers from the Turkish State Railways for the port of Basra on the Gulf. This might be an alternative to putting the containers on to the Iranian State Railways for a Persian port, but any negotiation would have to be done by a German shipowner say, or a Greek or an Indian.

The International Union of Railways in conjunction with its opposite number in Moscow is working on a really ambitious scheme for traffic wagon control, to cover the whole of the Euro-Asian land mass. The first step was to give all the carriages and wagons that run in international service a twelve-digit number for computer use: some railways went so far as to re-number all their rolling stock. The re-numbering was finished in 1968 and today coaches and wagons to be seen in London, Sofia, Baghdad and Peking, as typical centres, all have numbers in the same series. Railways on offshore islands with incompatible railway gauges such as Ireland, Japan and those of Indonesia are not in the scheme, nor are the railways of India and Burma behind the Himalayan mountain barrier and for the time being the politically isolated countries of Israel, South Korea, South Vietnam, Cambodia and Thailand have yet to join. Two electronic systems for scanning and recording wagon numbers at speeds of up to 60 mile/h for feeding into computers have been selected by the International Union of Railways as the most suitable for widespread use. These systems have been given an extended trial on the test track of the Czechoslovakian State Railways near Prague in all sorts of conditions and weathers. Meanwhile, tiring of waiting for the internationally recommended scanning system, some railways are installing systems of their own choice, notably British Rail and the Italian State Railways.

This excursion into the railway applications of computers really belongs to a book on railway management, a subject that this volume does not deal with. Nor can the sales and marketing side of railways be dealt with here, even though bringing in the traffic is vital to the continued existence of the railway. Many books have been written on management, sales and marketing to which the reader is referred, the principles outlined in them apply equally to the business run by railwaymen.

This book has confined itself to the impact of modern technology on the railway and to the unorthodox railways the technology makes possible. Technology is fundamental to modern transport and all the razzmatazz put out by politicians, university pundits, planners, economists, management consultants, entrepreneurs and many others on this subject at bottom usually depends on the answers to two engineering questions. First, 'will it work?' and second, 'how much does it cost?'. Cheaper and more reliable transport is ever the aim and now the railway is in a position to make substantial contributions to both requirements. In particular, the way is open to shed much expensive labour—probably one-third of the staff or more. Rudyard Kipling wrote: 'Romance brought up the nine-fifteen'. Taking this quotation out of context and the words at face value, romance will still be bringing up the nine-fifteen in future; romance, enterprise, hard work and railway engineering adventure.

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